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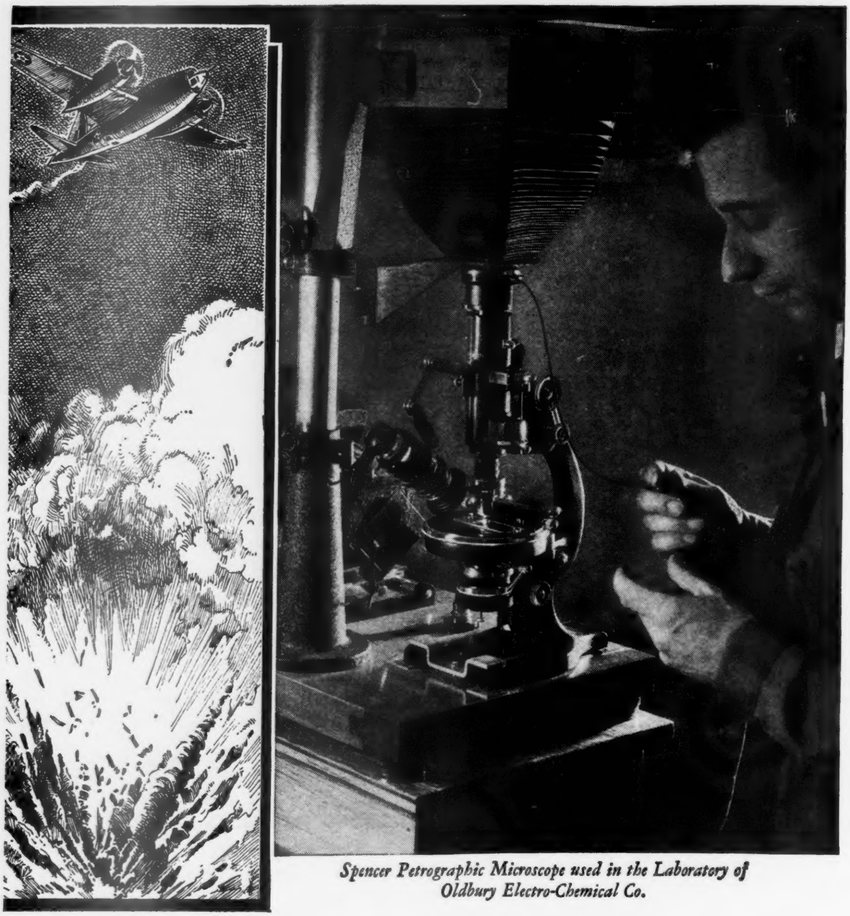

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FEBRUARY, 1943

FRANCISCAN-KNOXVILLE PROBLEM*

NICHOLAS L. TALIAFERRO**
Berkeley, California

ABSTRACT

Franciscan and Knoxville rocks are widely distributed and attain a great thickness in the Coast Ranges of California and southwestern Oregon. In California they crop out in a known area of at least 14,000 square miles and are estimated to underlie an additional 16,000 square miles, thus covering approximately one-fifth of the total area of the state. Even so, this is probably less than half of their original extent. The geosyncline in which they were deposited was more than 700 miles in length and probably more than 100 miles in width. Owing to removal of the higher beds by erosion, fully 90 per cent of the present outcrops are Franciscan, as that term is usually used. The name Franciscan implies a lithologic assemblage characterized by arkosic sandstones, radiolarian cherts, pillow lavas, basic and ultrabasic intrusives, and pneumatolytic metamorphics (glaucophane and related schists). Unfortunately, the Franciscan has been made a catch-all for several wholly unrelated formations in southern California and the Sierra Nevada. If many of the correlations proposed were correct the name Franciscan would have neither stratigraphic nor lithologic significance and should be abandoned; it would be practically synonymous with the lower Mesozoic. Such unjustifiable correlations have unnecessarily confused an already complex problem. Evidence is presented to show that the Franciscan is not a catch-all of uncertain age and of no stratigraphic significance but, together with the Knoxville, occupies a comparatively short space of geologic time (Tithonian, Upper Jurassic) and is of great stratigraphic significance.

The term Knoxville is used here for those sediments and volcanics above what is commonly regarded as Franciscan and below the Lower Cretaceous. As usually described, the Knoxville consists of a thick series of shales, with minor amounts of sandstone and conglomerate. This is an adequate description of the bulk of the Knoxville in many localities but it ignores certain important rocks in some localities and entire sections in other regions. The Stanley Mountain region in southern San Luis Obispo County may be cited as an example. Here the lithologic composition is both Franciscan and Knoxville, arkosic sandstones, dark clay shales, pillow lavas, radiolarian cherts, and basic and ultrabasic intrusives, but the fauna is definitely that of the thick section of Knoxville shales in other parts of the state. Furthermore, pillow lavas, radiolarian cherts, and basic and ultrabasic intrusives are common in the Knoxville in many regions. Although there is a lithologic difference between Franciscan and Knoxville in many areas this difference is not universal and the types commonly regarded as Franciscan are in many places found in what must be called Knoxville on the basis of the fauna.

This common lithologic similarity results from the fact that the widespread volcanism that in most places began well down in the Franciscan persisted for a longer time in some regions than in others. Thus volcanism, with the attendant formation of radiolarian cherts, continued practically to the close of the Jurassic in some localities; at the same time, dark clay shales usually regarded as characteristic of the Knoxville, and with a typical Knoxville fauna, accumulated in areas free from volcanism. Volcanism neither began nor ended at the same time everywhere nor was it of equal intensity throughout the late Jurassic geosyncline in which the Franciscan and Knoxville accumulated.

* Manuscript received, November 13, 1942. Read before the Pacific Section of the Association, at Los Angeles, October 16, 1941.

** Professor of geology and chairman, department of geological sciences, University of California, Berkeley.

The profound unconformity between the Franciscan and the Knoxville, reported by many writers, is a myth; it is unsupported by field evidence. The Lower Cretaceous, which is lithologically similar to the sedimentary part of the Knoxville, is commonly confused with the latter and the unconformity, or disconformity, at its base has been the chief cause of the reported unconformity at the base of the Knoxville.

The Knoxville is regarded by the writer as an upper phase of the Franciscan. Since these names have become fixed in the literature, and since it is not desired to introduce new terms, it is suggested that the name Franciscan-Knoxville group be used for the entire sequence. No confusion should be caused by such usage; local formational names may be given as the result of adequate mapping.

The Franciscan-Knoxville sequence accumulated in a geosyncline that came into existence as a result of the Nevadan orogeny (Portlandian) that strongly folded the earlier Mesozoic sediments of the present Sierran region. As the ancestral Sierra Nevada emerged, a long and broad trough was formed and the site of the present Coast Ranges was flooded for the first time in the Mesozoic. At the same time a high and rugged land mass came into being, or an already existent land mass was greatly uplifted, west of the present coast line. The character of the sediments in the Franciscan-Knoxville group and the direction from which they were derived strongly support the concept of this western land mass; seismologic evidence also lends support. In the great trough east of this rugged range and west of the emerging Sierra Nevada the Franciscan-Knoxville rocks accumulated; this marks the beginning of the earliest readily decipherable history of the present Coast Ranges. During the early history of the geosyncline, arkosic sandstones accumulated rapidly; geosynclinal sinking kept pace with deposition. As the land mass was worn down, the stream gradients decreased, and predominant mechanical disintegration gave way to predominant chemical decomposition, a gradual change took place in the character of the sediments supplied. The arkosic sandstones pass upward into the dark clay shales characteristic of the Knoxville in many localities. Thus the Franciscan and the Knoxville form a normal depositional cycle. This cycle is, of course, complicated by widespread volcanism and the formation of chemical sediments such as the cherts. These may appear at almost any horizon but they are most abundant in the upper part of the Franciscan. Thus the Franciscan-Knoxville group is not only characterized by certain distinctive lithologic types but also by the sequence in which these appear.

Local disturbances took place on the margins of the geosyncline during the accumulation of the thick Franciscan-Knoxville group but at no time was the entire trough affected. There are local discontinuities in deposition but there is no record of widespread diastrophism until the beginning of the Lower Cretaceous. The geosynclinal margins may have been modified but deposition was continuous over most of the trough.

There is a very general misconception regarding the stage of alteration of the Franciscan due in large measure to its commonly disordered appearance and the presence of schists. The chief causes of the disordered appearance in many localities are the heterogeneous nature (flows and chemical sediments interbedded with normal clastics and numerous intrusives) and the many periods of diastrophism suffered by the Franciscan during the Cretaceous and Tertiary. The Franciscan has been folded and faulted repeatedly and the sediments have been crusted against the more resistant volcanics and intrusives, resulting in extensive shearing and slickensiding in many regions. Where volcanics and intrusives are scarce or absent the sediments have been little altered except by depth of burial.

The glaucophane and related schists can not be regarded as evidence for extensive regional metamorphism as they are confined to the borders of intrusives and are clearly the result of local pneumatolytic contact action.

Introduction

Franciscan and Knoxville have a wide distribution and attain a great thickness in the California Coast Ranges north of Santa Barbara yet there is little agreement as to their age limits and relation to each other, and to other Mesozoic units in the state. Briefly, the problem is the age of the Franciscan and the extent of the geosyncline in which it was deposited, the relation of the Franciscan and Knoxville, and the relation of both to other units in California, especially to the crystalline basement complex of the Coast Ranges and the Sierra Nevada, and to the Lower Cretaceous. These are problems of fundamental importance not only in the geologic history of the Coast Ranges but of the state as a whole.

The problem, rendered obscure by a very complex subsequent history involving a number of periods of folding and faulting, erosion and deposition, has been

further complicated by unjustifiable correlations, many of them made with little first-hand knowledge, either of the Franciscan or the units with which it has been correlated.

Many widely divergent suggestions have been made as to the age of the Franciscan. When it appears on the legend of a geologic map it is usually given as Jurassic (?) but there has been little agreement as to its position in that long period. It has been suggested that it includes beds of Permian and Triassic, as well as of Jurassic age. On the other hand, it has been assigned to the interval between the Jurassic and Cretaceous. It has been correlated with much older sediments and volcanics in the Sierra Nevada because of supposed lithologic similarity and with metamorphosed rocks in southern California simply because, in one case, the rocks are supposed to be Triassic, and, in the other case, because of the presence of glaucophane schists.

If these various correlations and suggestions as to the age are true the Franciscan would have no stratigraphic significance but would be a catch-all, such as the Calaveras of the central Sierra Nevada. If no lower age limit could be assigned the name would only convey the idea of a particular lithologic assemblage. When the various units that have been correlated with the Franciscan are considered, even the distinctive lithology, supposed to be characteristic, disappears. Anyone familiar with the literature realizes the almost hopeless confusion of the problem at the present time.

For more than 20 years the writer has studied the stratigraphy and structure of the bedrock complex of the Sierra Nevada, and has mapped large areas in the central Coast Ranges. Reconnaissance trips have been made throughout the central and northern Coast Ranges and in southwestern Oregon. One of the results of this work has been the conclusion that the Franciscan is not a heterogeneous assemblage of uncertain age and little or no stratigraphic significance but, together with the Knoxville, a unit of known age and representing an orderly sequence of events throughout the limits of its deposition. This conclusion was reached wholly on stratigraphic and physical grounds since no direct evidence was afforded by fossils at the time. Supporting paleontological evidence has resulted from the painstaking work of C. L. Camp on two saurian skulls found in boulders of Franciscan chert. These will be referred to in a later section.

In this paper the rather voluminous literature on the Franciscan and Knoxville is reviewed, a brief description of both given, and the evidence regarding the basin in which they were deposited, their relations to each other, and their place in the geologic history of California presented. With the exception of the sandstones and schists only brief descriptions of the lithologic types are given. Since arkosic sandstones are the predominant rock type in the Franciscan and as they are of importance in a discussion of the source and conditions of derivation and deposition of the Franciscan clastics, they are described at greater length than the more exceptional rock types. A detailed description of the lithologic character of the Franciscan and Knoxville will be given in a future paper.

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Historical Review

The Franciscan was first described by Blake[1] in 1855 as the sandstone of San Francisco; in 1856 he gave a more detailed account of its character and distribution in the Pacific Railroad report.[2] This report is accompanied by a map of the central San Francisco Bay region, dated 1853, showing the distribution of the San Francisco sandstone and the serpentine, which he regarded as an intrusive body. Although this map gives a reasonably accurate picture of the distribution of the Franciscan in the vicinity and includes no later beds it is clear from the text that Blake included both Cretaceous and Tertiary sediments under the name San Francisco sandstone in other parts of the state. His statement of the distribution is as follows.

> . . . the wide extent of the formation has been made known by observation; it forms the greater part of the hills and mountains around the bay, and, so far as explored, a considerable part of the mass of the Coast Mountains. It is believed to be the most extensive and highly developed formation of the California coast, and may appropriately be known as the San Francisco or California sandstone. (1856, p. 153.)

Blake was reluctantly forced to the conclusion that the San Francisco sandstone was of Tertiary age because of Tertiary fossils in blocks of sandstone washed up on the beach and which he thought to have been broken from submerged ledges of the same formation but which, actually, were from outcrops of the Merced sandstone (Pliocene). In 1865 Whitney[3] described the sandstones, jaspers, serpentine, diabase, and schists and considered them to be silicified and serpentinized Cretaceous sediments. He occasionally mentions the San Francisco sandstone, but usually refers to the entire assemblage as "the metamorphic rocks" or "metamorphosed Cretaceous." That "the metamorphics" are not greatly altered in many places was recognized and commented upon, but no explanation given or no separation of the various units made. Whitney recorded the discovery of an *Inoceramus* in a barge load of rock from Alcatraz Island and regarded this as convincing proof of the Cretaceous age of "the metamorphics."

[1] W. P. Blake, "Observations on the Characters and Probable Geologic Age of the Sandstone of San Francisco," *Proc. Amer. Assoc. Adv. Sci.*, Vol. 9 (1855), pp. 220–22.

[2] *Idem, Report of Explorations in California for Railroad Routes*, 33d Congress, 2d Sess., Geol. Rept. (1856).

[3] J. D. Whitney, *Geological Survey of California*, "Geology." Vol. 1 (1865).

FIG. 1.—Outline map of California and southern Oregon showing counties mentioned in text.

Apparently little attention was paid to these rocks until Becker's work on the quicksilver deposits 2 decades later. In 1885 Becker,[4] following Whitney, regarded the various rocks as metamorphosed Lower Cretaceous. The next year he discussed the Cretaceous metamorphic rocks of California[5] and stated that the phthanites (cherts) were silicified Neocomian (Lower Cretaceous) shales and that the serpentines, diabases, and basalts were metamorphosed sandstones. He believed that widespread metamorphism had taken place at the close of the Neocomian and that the "Chico" (Upper Cretaceous) sediments were the first deposits laid down after this diastrophism.

Becker gave the name "Knoxville series" to all the sediments and "metamorphics" (serpentines, diabases, and cherts) in the vicinity of the village of Knoxville and the Redington Quicksilver Mine and correlated them with the Mariposa slates of the gold belt in the Sierra Nevada. In the sense used by Becker the "Knoxville series" included the Franciscan and, as shown on the geologic map of the Knoxville district,[6] the Paskenta stage of the Lower Cretaceous, as well as the sediments now known as Knoxville. In the legend on this map the sediments are given as "Neocomian" and the serpentines, diabases, schists, and cherts as "Neocomian, metamorphic."

The early workers gave the impression that widespread and intense metamorphism had affected a large part of the rocks of the Coast Ranges, a picture that is not consistent with the actual conditions, but one which has persisted regarding the Franciscan in the minds of some workers until the present time. This concept has done much to confuse an already complex problem.

Fairbanks,[7] in 1892, was the first to challenge the earlier views and to suggest a pre-Cretaceous age of the so-called "Cretaceous metamorphics" of the Coast Ranges. He also presented evidence to show that the serpentine is an intrusive rock and not an altered sediment as was maintained by Whitney and Becker. Fairbanks again discussed the pre-Cretaceous metamorphics in 1893[8] and presented a map showing their distribution. It is clear, both from the map and the text, that no distinction was made between the metamorphics of the Coast Ranges, Klamath Mountains, and Sierra Nevada. No specific names were applied to any of the units of this heterogeneous assemblage of rocks and no statement was made regarding the age of the "metamorphics" of the central Coast Ranges, other than that they were pre-Cretaceous.

Ransome, in 1893–94, in describing the rocks of Point Bonita[9] and Angel

[4] George F. Becker, "Notes on the Stratigraphy of California," *U. S. Geol. Survey Bull. 19* (1885).

[5] *Idem*, "Cretaceous Metamorphic Rocks of California," *Amer. Jour. Sci.*, 3d Ser., Vol. 31 (1886), pp. 348–57.

[6] *Idem*, "Geology of the Quicksilver Deposits of the Pacific Slope," *U. S. Geol. Survey Mon. 13* (1888).

[7] H. W. Fairbanks, "The Pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges," *Amer. Geol.*, Vol. 9 (1892), pp. 153–66.

[8] *Idem*, "Notes on a Further Study of the Pre-Cretaceous Rocks of the California Coast Ranges," *Amer. Geol.*, Vol. 11 (1893), pp. 69–84.

[9] F. L. Ransome, "The Eruptive Rocks of Point Bonita," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1 (1893), pp. 71–114.

Island,[10] used the name San Francisco sandstone for the clastic sediments but did not discuss their age. In a note appended to the Angel Island paper, Hinde gave the results of an examination of several radiolarian cherts, but did not reach a positive conclusion as to their age. Regarding the radiolaria Hinde states:

> The forms which can be thus imperfectly identified are too few to permit of any satisfactory comparison with the fossil radiolaria from other localities. The character of the rock and the mode of preservation appear to be very similar to what is met with in the red radiolarian jaspers and cherts described by Dr. Rüst from the Tyrol, Switzerland, Hungary and other places. Thus, for instance, in the upper Jurassic or Tithon beds of Allgäu in the Tyrol, there are red jaspers, filled, like these Angel Island red cherty rocks, with radiolaria. The most distinctive feature in the Californian radiolaria is the number and variety of forms of the genus *Dictyomitra* present in it, and it is not without significance that this genus is also abundantly represented in the Jurassic and Cretaceous radiolarian jaspers and cherts mentioned above.

It is interesting that this is the first suggestion of a possible Tithonian age for the Franciscan. From the foregoing it is apparent, however, that the correlation was largely based on lithologic similarity.

In 1895 Lawson[11,12] gave the name Franciscan series to a typical assemblage in the San Francisco Peninsula and pointed out its wide distribution in the Coast Ranges. He divided the series into five parts and stated that the lower member rested on the Montara granodiorite, which he thought to be Upper Jurassic and equivalent to the Sierran batholithic masses. Later[13] it was found, from fossil evidence, that the supposed basal member of the Franciscan was Martinez (Paleocene). Actually this supposed basal member is largely Cretaceous unconformably overlain by infolded Martinez. In his earlier papers, Lawson made no positive statement as to the age of the Franciscan, but inclined toward the belief it was Lower Cretaceous, although Fairbanks previously had presented evidence that it was pre-Cretaceous. In 1914 Lawson[14] tentatively suggested that the Franciscan might occupy the interval between the Jurassic and the Cretaceous; he was forced to this suggestion by his belief in the late Jurassic age of the granodiorite of the Coast Ranges. This question has been discussed previously[15,16] and need not be reviewed here except to say that there is good evidence that the Coast Range granodiorites are earlier than the Jurassic.

[10] *Idem*, "The Geology of Angel Island, with a Note on the Radiolarian Chert from Angel Island and from Buriburi Ridge, San Mateo County, California, by George J. Hinde," *ibid.*, Vol. 1 (1894), pp. 193–240.

[11] A. C. Lawson, "A Contribution to the Geology of the Coast Ranges," *Amer. Geol.*, Vol. 15 (1895), pp. 342–56.

[12] *Idem*, "Sketch of the Geology of the San Francisco Peninsula, California," *U. S. Geol. Survey Ann. Rept. 15* (1895), pp. 399–476.

[13] *Idem*, "San Francisco, California," *U. S. Geol. Survey Geol. Atlas Folio 193* (1914).

[14] *Idem*, *op. cit.* (1914), p. 7.

[15] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Bur. Min. Bull. 118*, Pt. 2 (1941), pp. 119–62.

[16] *Idem*, "Geologic History and Correlation of the Jurassic of California and Southwestern Oregon," *Bull. Geol. Soc. America* (in press).

In 1895 Fairbanks[17] proposed the name Golden Gate series for the Franciscan and stated it was pre-Cretaceous. Fairbanks gave a very clear and excellent statement of the character, distribution, and stratigraphic position of these rocks; however, his name "Golden Gate series" appeared after Lawson's term "Franciscan series" which has been universally adopted.

In 1895 Ashley attempted to show that Blake's San Francisco sandstone was Miocene, stating that it could be traced continuously from San Francisco to Pescadero.[18] Evidently several sandstones of very different ages were considered as one formation.

Fairbanks' statement in 1904[19] regarding the age and position of the Franciscan and Knoxville is typical of the ideas of the time. He states:

> The position of the Franciscan group in the geologic scale is readily determinable, partly because of the scarcity of fossils and partly because of the difficulty experienced in ascertaining its relation to the Knoxville group, the lowest recognized Cretaceous. The formation has been shown to occur unconformably beneath the Knoxville, and the paleontologic evidence, though very incomplete, is sufficient to make it clear that the beds cannot be older than the Jurassic. The group occupies the same relation to the Knoxville in the Coast Ranges as do the Mariposa slates in the Sierra Nevada and Klamath Mountains to the Knoxville on their borders, and is therefore provisionally referred to the Jurassic.

Fairbanks was forced by the Geological Survey to call the Franciscan the San Luis, and the Knoxville the Toro, names that have now been abandoned.[20,21] However in the text the names Franciscan and Knoxville are used, as may be seen from the foregoing quotation.

The Toro, as used by Fairbanks, includes both Upper Jurassic and Lower Cretaceous beds separated by a pronounced unconformity. In places the Lower Cretaceous rests on the Upper Jurassic part of the Toro, the Knoxville as used at present, but it commonly overlaps the Knoxville and rests on the Franciscan with a basal conglomerate filled with débris of the Franciscan and Knoxville. This is the unconformity between the Franciscan and the "Knoxville" mentioned by Fairbanks. The Upper Jurassic part of the Toro is Knoxville, as used here, and is an upper, shaly part of the Franciscan.

Diller,[22] in 1907, named the Dothan and Galice in southwestern Oregon and correlated the Galice with the Mariposa, and the Franciscan with the Dothan. Since he believed the Galice to be older than the Dothan, in spite of their field relations, the Franciscan was younger than the Mariposa but older than the

[17] H. W. Fairbanks, "The Stratigraphy of the California Coast Ranges," *Jour. Geol.*, Vol. 3 (1895), pp. 415–33.

[18] G. H. Ashley, "Studies in the Neocene of California," *Jour. Geol.*, Vol. 3 (1895), pp. 434–545.

[19] H. W. Fairbanks, "San Luis, California," *U. S. Geol. Survey Geol. Atlas Folio 101* (1904), p. 2.

[20] M. Grace Wilmarth, "Names and Definitions of the Geologic Units of California," *U. S. Geol. Survey Bull. 826* (1931).

[21] *Idem*, "Lexicon of the Geologic Names of the United States," *ibid.*, *Bull. 896* (1938).

[22] J. S. Diller, "The Mesozoic Sediments of Southwestern Oregon," *Amer. Jour. Sci.*, 4th Ser., Vol. 23 (1907), pp. 401–21.

Myrtle. Since the writer[23] has discussed these correlations they need not be reviewed here except to say that he has shown that the Dothan is older than the Galice and that the Franciscan is younger than (and overlaps) both. Furthermore, both the Dothan and Galice have been converted into slates and schists and stand at high angles and the Franciscan in the same region is unmetamorphosed except locally on the contacts of basic and ultrabasic intrusives.

An interesting controversy arose during the mapping of the Santa Cruz region.[24] That part of the Franciscan lying in the northern part of the quadrangle was thought to be Knoxville (in the old sense of Lower Cretaceous) by Branner and Newsom but also it was obviously a part of the type section of the Franciscan, as defined by Lawson. Louderback and Arnold acted as a committee to harmonize the mapping and concluded that the disputed beds were Franciscan, a conclusion only tentatively accepted by Branner and Newsom. The confusion arose from the discovery of a boulder of conglomerate containing *Aucella piochii*, and other Upper Jurassic fossils, in the disputed area. This was thought to be the same conglomerate as that resting on the Franciscan in the region in very small residual patches and containing a Lower Cretaceous fauna. The same confusion resulting from the assignment of all the Knoxville to the Lower Cretaceous runs through the published reports of the time and has influenced many of the more recent ideas.

Stanton,[25] in 1895, discussed the fauna of the Knoxville and concluded it was Neocomian, although he recognized that some of the fossils might be Jurassic. In discussing the age of the Franciscan, Stanton states (p. 13):

> While it seems probable that they underlie the Knoxville beds and are unconformable with them, no section has yet been described in which their stratigraphic relations may be clearly seen. We may say then that the Knoxville beds rest on strata of different ages, from Carboniferous to probably Upper Jurassic, and that they are unconformable on the underlying strata at some places, and probably everywhere.

The upper part of the Knoxville, in the sense used by Stanton, is Lower Cretaceous, but the lower part is Upper Jurassic. The Lower Cretaceous, along the west side of the Sacramento Valley, the region in which Stanton collected, gradually overlaps both the Franciscan and Knoxville northward and finally rests on the Paleozoic.

Haug[26] was the first to point out the Upper Jurassic age of the lower part of the Knoxville. Haug's statement follows.

> Cependant, le travail de M. Stanton (U.S.G.S., Bull. 133, 1895) contient en outre

[23] N. L. Taliaferro, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *Bull. Geol. Soc. Amer.* (in press).

[24] J. C. Branner, J. F. Newsom, and Ralph Arnold, "Santa Cruz, California," *U. S. Geol. Survey Geol. Atlas Folio 163* (1909).

[25] T. W. Stanton, "Contributions to the Cretaceous Paleontology of the Pacific Coast," "The Fauna of the Knoxville Beds," *U. S. Geol. Survey Bull. 133* (1895).

[26] Emilé Haug, "Portlandien, Tithonique et Volgien," *Bull. Soc. Geol. France*, Ser. 3, Vol. 26 (1898), pp. 226–27.

plusieurs *Hoplites*, décrits comme espèces nouvelles, mais qui sont très voisins d'espèces du niveau de Stramberg, quelques-uns d'entre eux étant même très vraisemblement identiques à ces dernières. Il ne peut donc y avoir aucun doute que la partie inférieure des "Knoxville beds" corresponde au Portlandien supérieur de la region méditerraneéne.

Little attention appears to have been given this statement for a number of years.

Smith,[27] in 1909, believed the Franciscan to have been metamorphosed at the time of the Cordilleran (Nevadan) revolution and that the lower Knoxville was Upper Jurassic, but deposited after this orogeny. However, in 1910, Smith[28] placed the lower Knoxville in the Neocomian. In both publications he placed the Franciscan in the Jurassic, but suggested that it contained beds as old as the Triassic. He regarded the Franciscan as the equivalent of the early Mesozoic beds of the Sierra Nevada that were deformed at the time of the Nevadan revolution.

Although Lawson did not reach a positive conclusion as to the age of the Franciscan he made a number of significant observations regarding the relation of the Knoxville (which he considered to be basal Lower Cretaceous) to the Franciscan and the nature of the surface on which the Knoxville was deposited. He pointed out that, in the San Francisco Bay region, the Knoxville everywhere rests on the Franciscan and nowhere overlaps it onto older rocks. The writer has found this to be true for the state as a whole. The lower (Upper Jurassic) Knoxville nowhere transgresses the Franciscan, but the upper (Lower Cretaceous) Knoxville transgresses both in northern California. He also noted the general absence of coarse detritus at the base of the Knoxville.

The occurrence of only small deposits of conglomerate or other coarse detrital beds at the base of the Knoxville, and the entire absence of such beds in many sections, show that peculiar conditions attended the beginning of the Cretaceous depression. The coarse sandstones and conglomerates which are usually spread over a sinking continental slope by a transgressing sea are here but very feebly if at all represented.[29]

He interpreted this to mean that extensive peneplation had taken place and that the interval between the Franciscan and Knoxville was long.

Tolman,[30] in 1915, stated that the Franciscan and Mariposa were of the same age and had been deposited in the same trough, the former in the western part and the latter in the eastern part and that both were derived from the ancestral Sierra Nevada. The writer already has discussed the trough in which the Mariposa, and older Mesozoic beds of the Sierra Nevada, were deposited and has shown it to be pre-Franciscan; evidence also has been presented indicating that the Mariposa was derived from the west and not from the east.[31]

[27] J. P. Smith, "Salient Events in the Geologic History of California," *Science*, New Ser., Vol. 30 (1909), p. 347.

[28] *Idem*, "The Geologic Record of California," *Jour. Geol.*, Vol. 18 (1910), pp. 216–27.

[29] A. C. Lawson, "San Francisco, California," *U. S. Geol. Survey Geol. Atlas Folio 193* (1914), p. 19.

[30] C. F. Tolman, Jr., "Geology of the West Coast Region of the United States," *Nature and Science on the Pacific Coast*, pp. 41–61. Paul Elder and Company, San Francisco (1915).

[31] N. L. Taliaferro, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *Bull. Geol. Soc. America* (in press).

Davis,[32] in 1918, discussed all the evidence, available at that time, relative to the age of the Franciscan, but, because of the conflicting evidence and the correlations that had been proposed, was unable to come to a definite conclusion. He pointed out that if the granodiorites of the Coast Ranges were of the same age as those of the Sierra Nevada, the Franciscan, which he recognized as post-Coast Range granodiorite, would have to occupy the interval between the Jurassic and Cretaceous. Davis considered that this interpretation was supported by Diller's (1907) correlation of the Dothan of southwestern Oregon with the Franciscan; this correlation has been discussed previously. Davis suggested that possibly the Franciscan might be Triassic, largely on the basis of lithologic similarity with Triassic rocks in Alaska, but recognized that this was not a safe basis for correlation. His final statement (p. 16) follows.

> The great uncertainty as to the age of the Franciscan is not wholly due to our lack of knowledge of the relations of the Coast Range granite and the absence of characteristic fossils in the Franciscan itself. The uncertainty regarding the age of the Knoxville adds greatly to the difficulty.

As stated by Davis, a serious obstacle in the way of reaching a conclusion as to the age of the Franciscan was the uncertainty regarding the Knoxville and a general misunderstanding as to what was meant by the term. Although even at that time there was a tendency to regard the lower part of the Knoxville as Upper Jurassic, the term was still used for the thick shale section along the west side of the Sacramento Valley and included not only Upper Jurassic beds but all of the Lower Cretaceous as well. Because of the somewhat peculiar nature of the break between the Upper Jurassic part of the Knoxville and the lithologically similar Lower Cretaceous beds, the nature of which is made clear in a later section, they were usually regarded as parts of one uninterrupted depositional cycle. Haug, who first stated that the lower part of the Knoxville was Upper Jurassic, also stated that the major Mesozoic diastrophism occurred before the deposition of the lower Knoxville and that the Upper Jurassic part of the Knoxville graded upward into the Neocomian as was supposed to be the case in the Mediterranean region. This seems to have been the belief even of those who considered the lower part of the Knoxville to be Upper Jurassic and it is this belief that gave rise to the idea that the Knoxville rests unconformably on the Franciscan. The Lower Cretaceous part of the original Knoxville actually does rest unconformably on the Franciscan in many places, but the Upper Jurassic part of the original Knoxville does not.

Anderson[33,34] was one of the first to point out the differences in the faunas of

[32] E. F. Davis, "The Franciscan Sandstone," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11 (1918), pp. 6–16.

[33] F. M. Anderson, "Jurassic and Cretaceous Divisions in the Knoxville-Shasta Succession in California," *California State Div. Mines Rept. 28 of the State Min.* (1932), pp. 311–28.

[34] *Idem*, "Knoxville-Shasta Succession in California," *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 1237–70.

the lower and upper Knoxville and the disconformity between them along the west side of the Sacramento Valley. His division of the original Knoxville into the restricted Knoxville of Upper Jurassic age and the Paskenta of Lower Cretaceous age did much to clarify the situation as far as the Knoxville is concerned. The term Knoxville is used in this paper as defined by Anderson, that is, as the Upper Jurassic part of the original Knoxville. The upper part of the original Knoxville is the Paskenta stage of the Lower Cretaceous.

The late R. D. Reed did a great service to the geology of California by his broad treatment of the subject and his clear statement of the unsolved problems. He was thoroughly familiar with the published reports on the Franciscan and Knoxville and, with characteristic insight, pointed out certain significant facts regarding their relationship, even though handicapped by the restricted state of knowledge of the Knoxville and the rather general belief that it was Lower Cretaceous. Regarding the supposed pre-Cretaceous deformation of the Franciscan he stated:

> It involved crumpling, faulting, metamorphism over large areas, and a great amount of igneous intrusion, all without much uplift of the affected rocks above drainage level. However difficult the adoption of such a hypothesis may seem, it is not at all inconsistent with the fact that the next younger formation, the Knoxville, is a dark shale with very little coarse detritus where best known, and with little but a fairly rich marine fauna to distinguish it from much of the Franciscan itself. So little evidence of a mountain-making period is there between Franciscan and Knoxville, in fact, that most of the early workers classed both as Lower Cretaceous. Since the two came to be considered distinct formations, the problem of their relation has remained one of the outstanding puzzles of California geology.[35]

Reed, however, unnecessarily confused an already complex problem by postulating separate basins of deposition of the Franciscan and by unwarranted correlations. The writer[36] has briefly stated his objections to the concept of separate basins of deposition; evidence against such a hypothesis is presented in a later section of this paper. Reed correlated the Franciscan of the Coast Ranges with certain beds, briefly described by the writer,[37] in the Sierra Nevada on the basis of the presence of radiolarian cherts and pillow basalts (Reed, 1933, pp. 85–86, 97). The lithologic similarity of the Tuolumne[38] to certain phases of the Franciscan was recognized by the writer, but their correlation was never suggested since even at that time (1931) the Tuolumne (Amador) was considered to be older than the Franciscan. Pillow basalts and radiolarian cherts occur in the Sierra Nevada in association with limestones containing upper Paleozoic fossils; these rocks are unconformably overlain by the Tuolumne (Amador). The basal con-

[35] R. D. Reed, *The Geology of California,* Amer. Assoc. Petrol. Geol. (1933).

[36] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges," *California State Min. Bur. Bull. 118*, Pt. 2 (1941), p. 124.

[37] *Idem,* "Stratigraphy of the Bedrock Complex of the Sierra Nevada of California" (abstract), *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 233–34.

[38] The name Tuolumne has been abandoned because of its slightly earlier use by Calkins for certain plutonic rocks in the Yosemite region and the term Amador substituted in its place.

glomerate of the latter contains abundant débris of the Paleozoic rocks. Thus in the Sierra Nevada there are at least two sets of rocks, one upper Paleozoic, the other Middle or Upper Jurassic, which contain volcanics and chemical sediments similar to those in the Franciscan. It would be just as logical to correlate these Paleozoic and Jurassic rocks, separated by a profound unconformity, with each other as to correlate either or both with the Franciscan. It is such correlations, based only on supposed lithologic similarity, that have unnecessarily complicated the problem of the age and position of the Franciscan. The writer hopes that he has made it perfectly clear that he had no intention of suggesting that the Tuolumne (Amador) was a correlative, either in whole or in part, of the Franciscan. The writer has correlated the Tuolumne (Amador) with the Dothan of southwestern Oregon and the Mariposa with the Galice; both are unconformably overlain by the Franciscan. Reed's statement that "the Tuolumne group is thus analogous in stratigraphic position, as in lithologic character, to the Franciscan series" could only be true if the Sur series were of the same age as the older Sierran metamorphics and the Knoxville the equivalent of the Mariposa. Anyone even slightly familiar with the geology of California must recognize that such correlations have no factual basis.

An even more extreme view of the Franciscan was adopted by Reed and Hollister in 1936.[39] In their Table I, "Structural History of Southern California," the Franciscan is shown as occupying the time between the Appalachian and Nevadan orogenies; hence, it would extend from upper Paleozoic to Middle Jurassic. (The Nevadan orogeny appears to have been misplaced in this table.) They state (p. 5):

> The Franciscan stage included a part, and perhaps nearly the whole, of the Triassic and Jurassic periods.

The following statement is made in defense of their treatment of the Franciscan.

> They hold that the Franciscan is dominantly marine, that it probably includes both Triassic and Jurassic deposits, that it is the correlative of the phyllites and slates of the Santa Monica and Santa Ana mountains but represents a different facies. They defend the policy of treating the Franciscan as a unit, but only on the ground that no other treatment is possible at the present time.

From the foregoing historical review it is obvious that there is ample precedent for regarding the Franciscan as both Triassic and Jurassic, but the inclusion of the Santa Monica slates and contact metamorphics is sanctioned neither by precedent nor lithologic similarity. If the term Franciscan is used as synonymous with the entire lower half (or more) of the Mesozoic then the inclusion of such diverse rocks as the Santa Monica slates, the Catalina metamorphics, and the Tuolumne (Amador) is justified; in no other way may such correlations be justified. Such statements obscure and mystify the problem. If true, the name Franciscan should be abandoned, as it would cease to have even any lithologic

[39] R. D. Reed and J. S. Hollister, *Structural Evolution of Southern California*, Amer. Assoc. Petrol. Geol. (1936), pp. 5–6.

significance. The writer can see no justification for the attempt to include most of the Mesozoic (and older) rocks of the state in the Franciscan, even for the sake of a broad structural synthesis.

The published reports on fossils in the Franciscan are reviewed in a later section.

A review of the literature shows the great diversity of opinions that have been held regarding the age and relationships of the Franciscan. First reluctantly placed in the Tertiary by Blake, then in the Cretaceous by Whitney and Becker, it then became pre-Cretaceous on the basis of misinterpreted stratigraphic and paleontologic evidence. If there is any general opinion at the present time it would seem to be that the name Franciscan is practially synonymous with the lower half of the Mesozoic, a convenient unit of no stratigraphic significance.

The purpose of the present paper is to show that the Franciscan, together with the closely related Knoxville, represents a comparatively brief time interval and is a useful stratigraphic horizon. The history of the inception and growth of the geosyncline in which the Franciscan and Knoxville were deposited is of fundamental importance in the structural evolution of the Coast Ranges.

FRANCISCAN

DISTRIBUTION

The distribution and general character of the Franciscan are described before discussing its age and relations to other units.

The Franciscan is widely distributed in the Coast Ranges of California and southwestern Oregon from Santa Barbara County northward to Roseburg, Oregon, where it disappears beneath Eocene sediments and volcanics. The distribution of the Franciscan is well shown on the 1938 geological map of California, except in the Coast Ranges north of San Francisco Bay where it was necessary to leave large areas blank because of lack of definite information. Most of this region has been visited and it may be stated definitely that the greater part, south of the latitude of Eureka (41° N.) is underlain by the Franciscan, either as outcrops or beneath comparatively small infolded areas of Cretaceous and Tertiary sediments.

The wide distribution of Franciscan rocks in the Coast Ranges of California and Oregon indicates that the original basin of deposition was of great extent. If the rocks on Catalina Island and in the San Pedro Hills in southern California actually are Franciscan the original basin was even more extensive. However, these rocks are so different from the great bulk of the Franciscan, it is believed that they should be excluded until a more definite correlation is possible. The Catalina metamorphics have been described by Smith,[40] Woodford,[41,42] and Wood-

[40] W. S. T. Smith, "The Geology of Santa Catalina Island," *Proc. California Acad. Sci.*, Ser. 3, Geol., Vol. 1 (1897), pp. 1–71.

[41] A. O. Woodford, "The Catalina Metamorphic Facies of the Franciscan Series," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 15 (1924), pp. 49–68.

[42] *Idem*, "The San Onofre Breccia, Its Nature and Origin," *ibid.*, Vol. 15 (1925), pp. 159–280.

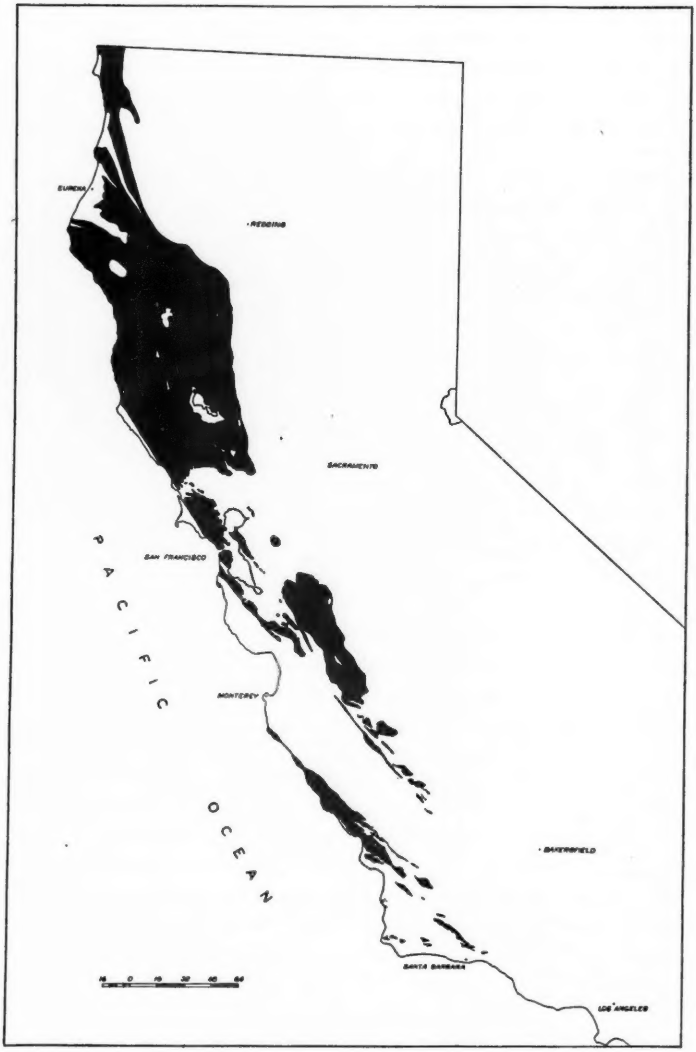

FIG. 2.—Outline map of California showing present distribution of Franciscan and Knoxville. Scale in miles.

ford and Bailey.[43] Smith did not suggest that they were Franciscan, but because of their similarity to certain contact pneumatolytic schists in the Franciscan usually it has been assumed that they actually are Franciscan. Woodford, who gave an excellent description not only of the schists on Catalina Island, but also the schist débris in the San Onofre breccia, tentatively correlated them with the Franciscan, although he recognized that they might be older. He states (p. 62, 1924):

> At this time, however, the correlation can be made only in the most general sense, indicating merely that these rocks belong to a great and perhaps heterogeneous group now called the Franciscan series. It may be that these metamorphic rocks belong to an ancient group which extends northward unconformably beneath typical Franciscan. This may be indicated in the middle Coast Ranges by pebbles of glaucophane schist and serpentine in Franciscan conglomerates.

Perhaps because of the title of Woodford's 1924 paper the tentative nature of the correlation and the alternative suggestion have been ignored by later writers and the Catalina metamorphics definitely correlated with the Franciscan.[44]

Woodford and Bailey pointed out the difference between the typical Franciscan and the schist fragments in the northward combination of the San Onofre breccia. They state:

> It is noteworthy that the Malibu San Onofre, though only 50 miles southeast of the Santa Barbara County exposures of Franciscan sandstone, shale and basalt, contains no unmetamorphosed examples of these Franciscan rocks. One wonders what sort of Franciscan, if any, may lie between Malibu and Santa Barbara.

The only possible basis for the correlation of the Catalina metamorphics and the Franciscan is the presence of glaucophane and related schists and serpentine, neither of which is an adequate criterion. Serpentines intrude pre-Franciscan rocks in the Sierra Nevada and are involved in the pre-Franciscan folding. Actinolite-titanite-albite schists which are identical with the pneumatolytic schists of the Franciscan, except for the presence of glaucophane, are developed on the margins of the ultrabasic intrusions in the Sierra Nevada. The presence of soda schists and serpentine can not be used as evidence for the equivalence of the Catalina metamorphics and the Franciscan. From the evidence of the actual outcrops of the metamorphics on Catalina Island and in the San Pedro Hills and the presence of blocks and fragments of the schists in the Miocene San Onofre breccia for a distance of 100 miles along the coast, the Catalina metamorphics must have had a wide distribution. It is suggestive that nowhere in the Franciscan, in its entire extent from Santa Barbara County into Oregon, are there any areas of schists more than a few miles in length. The wide extent of the Catalina metamorphics is in marked contrast to the very local development of pneumatolytic contact schists in the Franciscan and indicates a different origin for the two. The writer believes that it is necessary to show a closer relation between the Catalina metamorphics and the Franciscan before a correlation can be established. Any attempt at corre-

[43] A. O. Woodford and T. L. Bailey, "Northwestern Continuation of the San Onofre Breccia."

[44] R. D. Reed, *Geology of California* (1933), pp. 83–84.

lation must take cognizance not only of the schists but also of the general lack of metamorphism and definite lithologic sequence shown by the Franciscan throughout its extent in California and Oregon. It is not believed that a correlation has been established.

Excluding the Catalina metamorphics the Franciscan has a total outcrop area of at least 2,500 square miles in the Coast Ranges between Santa Barbara and San Francisco Bay. North of San Francisco Bay the areal extent is less certainly known but between the Bay and Lat. 40° N. Franciscan crops out in an area of approximately 8,100 square miles. Between Lat. 40° N. and the northern boundary of the state it is exposed throughout an area estimated to be at least 3,500 square miles. Thus the total outcrop area of the Franciscan in the Coast Ranges of California is approximately 14,000 square miles. These figures include outcrops of the Knoxville, but at least 90 per cent of the areas given are Franciscan. The Knoxville is included since, for reasons that are apparent later, it is impossible to separate the two in several regions.

South of San Francisco Bay it may be stated with reasonable certainty that Franciscan and Knoxville rocks either occur at the surface or underlie the surface rocks in an area of at least 12,300 square miles. Between San Francisco Bay and the northern border of the state they are either exposed or they underlie an area of at least 18,000 square miles. Thus these two late Upper Jurassic units underlie an area of more than 30,000 square miles in the California Coast Ranges, approximately one-fifth of the total area of the state. This is only a part of the original basin in which these beds were deposited.

Franciscan and Knoxville form the basement rocks in much of the northern Coast Ranges south of Eureka but in the central Coast Ranges there is a diagonal strip of variable width in which the basement, either exposed or overlain by late Cretaceous and Tertiary beds, is composed of Santa Lucia granodiorite, Sur schists, and Gabilan marble, rocks much older than the Franciscan. This area, which embraces the La Panza and Caliente mountains, the Carrizo Plain, the Gabilan Mesa, the Gabilan Range, and a large part of the Santa Cruz Mountains, has been called "Salinia" by Reed, who tentatively suggested it was a land mass during the deposition of the Franciscan and Cretaceous.[45] Although tentatively suggested in the text the accompanying paleogeographic maps show three separate basins of deposition for the Franciscan, the two largest being separated by the hypothetical land mass of "Salinia." The chief arguments in support of the existence of this land mass are the absence of Franciscan and Knoxville rocks and the supposed lack of Franciscan detritus in Cretaceous, Eocene, Oligocene, and lower Miocene sediments. There is nothing involved in the problem of the relation of the Franciscan and Knoxville to cause the writer to have any feeling against the existence of such a land mass during their deposition but field observations strongly indicate that "Salinia" did not come into existence until the late Cretaceous and was not finally outlined until the Eocene.

[45] *Op. cit.*, pp. 29–31, 91, Figs. 6, 16.

In the first place, the absence of Franciscan and Knoxville is strictly negative evidence and is not a valid argument for the nondeposition of these beds in the area. Furthermore, Franciscan débris is not uncommon in later rocks. It is quite true that the most conspicuous pebbles, cobbles, and boulders in the Cretaceous conglomerates in most areas are of granodiorite, pegmatite, quartzite, black chert, and the ubiquitous porphyries, but there are notable amounts of Franciscan rocks as well. The Cretaceous conglomerates on Quinto Creek may be cited as a specific instance. Clark[46] stated that these conglomerates were composed largely of Franciscan rocks. This was categorically denied by Reed who stated (p. 101):

> A painstaking search at this locality through several conglomerate beds, including the thick basal conglomerate, failed to discover any distinctively Franciscan types of pebble except a single one of red chert. . . . The Quinto Creek Cretaceous beds are accordingly similar to those found elsewhere.

The writer has examined the Cretaceous conglomerates, not only on Quinto Creek, but on the other creeks both north and south, and has found abundant pebbles, cobbles, and large blocks of Franciscan rocks in practically all of the exposures. A count was made of approximately 200 pebbles from the Cretaceous conglomerates on Quinto Creek with the following results.

	Per Cent		*Per Cent*
Granodiorite (Santa Lucia)	14	Quartz	3
Pegmatite (Santa Lucia)	8	Cretaceous limestone	1
Sur schists	4	Franciscan volcanics	35
Recrystallized black chert (Sur)	4	Franciscan gabbro and diabase	4
Quartzites (Sur)	8	Franciscan red and green chert	5
Old porphyries	14		—
			100

By actual count, therefore, Franciscan rocks constitute at least 44 per cent of the constituents of the conglomerate. Pebbles of Franciscan chert and sandstone are much more abundant in the Cretaceous conglomerates on El Puerto Creek than in those on Quinto Creek.

Franciscan débris is present in the Cretaceous conglomerates in a number of places in the Santa Lucia Range and predominates in some localities, as on Little Pico Creek, San Simeon Quadrangle, 3–4 miles up the creek from the coast; in the Piedras Blancas Quadrangle, midway between the coast and Pine Top Mountain; and in the northeastern part of the San Simeon Quadrangle, 3 miles northwest of Deer Flat. These are specific localities, chosen at random, and are reasonably accessible. The writer does not think that the presence of Franciscan débris in the Cretaceous of the Santa Lucia Range has anything to do with the question of "Salinia"; however, they serve to show that the common belief in the entire absence of Franciscan débris in the Cretaceous is erroneous.

The character of the Franciscan on the immediate borders of "Salinia" is of greater importance. The writer has studied the Franciscan in its full extent both east and west of "Salinia" and has seen nothing in the character of the sediments

[46] B. L. Clark, "Tectonics of the Valle Grande," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 227.

that would indicate derivation from a hypothetical land mass between them. If the Franciscan had been deposited in separate basins we would expect to find this condition reflected in the character of the sediments on both borders and a general coarsening of grain toward the margins of the land mass. It is true, of course, that the base of the Franciscan is not exposed and the nature of the basal beds is not known but there is nothing in the part exposed, which is fully 10,000 feet in thickness, to indicate that the eastern and western areas of the Franciscan were deposited in separate basins. The Franciscan sediments and volcanics on both sides of "Salinia" are practically identical both as to lithologic character and sequence; if there is a tendency to greater coarseness in any direction it is toward the coast in the western belt, away from, rather than toward, "Salinia." The pebbles in the Franciscan conglomerate in both the eastern and western belts are the same and are certainly not predominantly of rocks exposed in "Salinia." The most abundant pebbles are various porphyries, recrystallized black chert, and red, gray, and white quartzites. Granodiorite and pegmatite pebbles are present, but they are very scarce except near the present coast line. The predominant pre-Franciscan rocks now exposed in the La Panza Mountains, the Gabilan Range, and the Santa Cruz Mountains are granodiorite and marble, with minor amounts of schist; there is a marked difference between these rocks and the pebbles in the Franciscan conglomerates.

When the Knoxville and Lower Cretaceous are considered there is even less evidence to support the existence of an old land mass such as "Salinia." Fossiliferous Knoxville and Paskenta shales are present on both sides, commonly along the immediate borders and extending into the hypothetical land mass; there is no evidence of coarsening of the sediments except westward toward the present coastline.

The writer's arguments against the existence of a land mass in Franciscan and Knoxville time, resulting in deposition in two separate basins, may be summarized as follows.

1. Both Franciscan and Knoxville (and Lower Cretaceous as well) show the same general sequence and lithologic types in both regions.

2. There is no change in texture on either side toward this altogether hypothetical land mass. Any tendency toward coarser texture is toward the west, across "Salinia" and not toward it.

3. The débris in both the Franciscan and the Knoxville gives no evidence of having been derived from the rocks now making up "Salinia."

4. Both Franciscan and Knoxville débris is not uncommon in the Cretaceous.

5. Various lithologic units and structures in the Franciscan-Knoxville sequence terminate against the Gabilan mesa-Gabilan Range-Santa Cruz Mountain region, the site of "Salinia."

The writer can see no evidence indicating the deposition of the Franciscan in separate basins or for the existence of a land mass such as "Salinia" in the Upper Jurassic. This land mass did not originate until late in the Cretaceous and

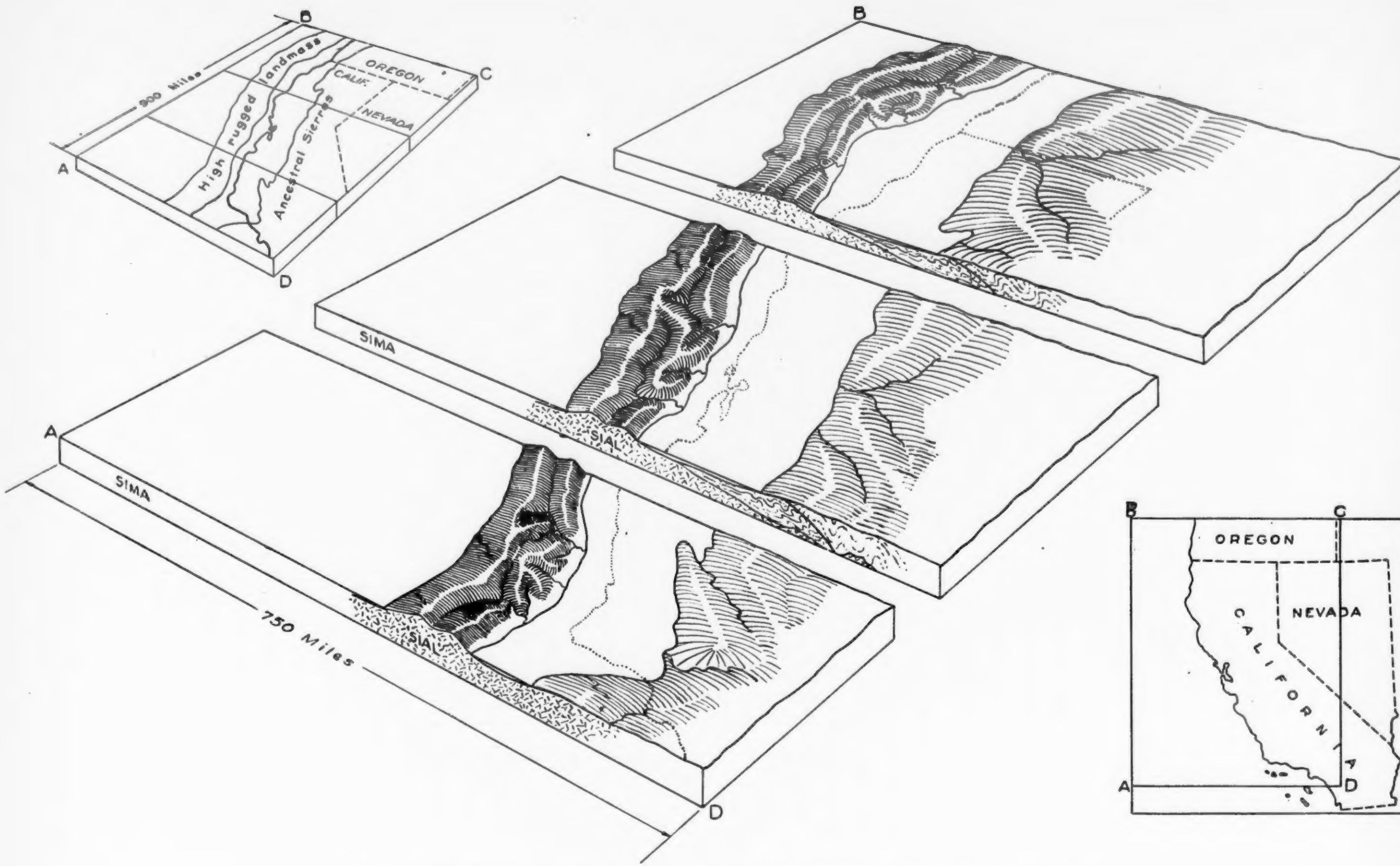

FIG. 3.—Block diagram of writer's concept of geosyncline in which Franciscan was deposited.

did not reach its full extent until the Eocene. The absence of Franciscan and Knoxville over a diagonal strip in the central Coast Ranges is believed to be due to removal by erosion rather than nondeposition.

The northern limit of the geosyncline is not known since Franciscan and Knoxville rocks disappear beneath Eocene sediments and volcanics near Roseburg, Oregon. Its southern limit is believed to have been slightly south of the latitude of Santa Barbara. There is no direct evidence regarding the western limit since the Franciscan extends to the present coast line. Little is known as to the eastern limit of the Franciscan beneath the Sacramento and San Joaquin valleys. However, there are three deep wells that have yielded some interesting information in this point. The deep well drilled by the Pure Oil Company, known as Chowchilla No. 1, 15 miles south of Merced and almost in the exact center of the San Joaquin Valley, passed directly from Cretaceous rocks into granodiorite, identical with the Sierran granodiorite, which is well exposed on the Mariposa River 21 miles northeast of the well. Thin sections of the bedrock from the well and from the Sierran granodiorite on the Mariposa River have been examined and compared and they are identical. A well was completed (October, 1941) by the Shell Oil Company about 7 miles south of the Pure Oil Company's well. This well, known as Chowchilla Farms 74-9, is located in Sec. 9, T. 11 S., R. 14 E. Basement rock was encountered immediately beneath the Cretaceous at 9,035 feet and the well was drilled to 9,062 feet. The basement was reported as actinolite schist, the inference being that the basement here is Franciscan. Through the kindness of E. F. Davis, the writer has been able to examine a core of the basement from 9,061 to 9,062 feet. This has been studied under the microscope and found to be a granular amphibolite identical with certain phases of the Sierra Nevada basement complex. Identical amphibolites are well exposed along the eastern edge of the San Joaquin Valley, 30 miles north northeast of the well, in the Indian Gulch Quadrangle about 5 miles north of the Yosemite highway. They represent metamorphosed volcanics interbedded with the Mariposa slates and intruded by granodiorite; they have been greatly metamorphosed by contact as well as by dynamic action. The basement rock encountered in this deep well is not Franciscan, but Sierran in character. In a deep well drilled on the south side of the Marysville Buttes, slightly east of the center of the Sacramento Valley, Sierran granodiorite, beneath Cretaceous sediments, was encountered at a depth of approximately 7,000 feet; an examination of the cores from this well shows that no Franciscan rocks are present. This, of course, is negative evidence since the Franciscan might have been deposited and then removed by erosion. The meager evidence available indicates an eastern thinning of the Franciscan, Knoxville and Lower Cretaceous from the Coast Ranges eastward into the great valley and an eastward overlap of these beds by the Upper Cretaceous. No Knoxville or Franciscan rocks, or equivalents are known in the Sierra Nevada. Tithonian fossils have been reported from Moffat's Bridge, Tuolumne River[47] but these fossils

[47] C. H. Crickmay, "Some of Alpheus Hyatt's Unfigured Types from the Jurassic of California," *U. S. Geol. Survey Prof. Paper 175b* (1933), pp. 51–64.

have been shown by the writer, largely based on determinations by S. W. Muller, to be lower Kimmeridgian (Mariposa) and not Tithonian.[48]

It is believed that the best available evidence indicates that the eastern margin of the geosyncline in which the Franciscan and Knoxville were deposited lay somewhere along the present great valley of California. Figure 3 is an attempt at a restoration of the Franciscan geosyncline; it is greatly idealized as, naturally, there is little information available as to the details of the configuration of the coast.

The writer's concept of the origin of the geosyncline, the nature of the adjacent highlands, and the environmental conditions of deposition is given in a later section.

LITHOLOGY

GENERAL STATEMENT AND SEQUENCE OF TYPES

The Franciscan is composed of lithologic types such as arkose, sandstones, dark sandy shales, dark clay shales, conglomerates, red, gray, and black limestones, foraminiferal and algal limestones, radiolarian cherts, pillow lavas, vesicular basalts, andesites, and dacites, and volcanic ash, breccias, and agglomerates. These are intruded by basalt, andesite, diabase, gabbro, and peridotite (ordinarily converted into serpentine); in places these intrusive bodies caused pneumatolitic metamorphism, with the local development of glaucophane and related schists. Although any of these diverse rock types may appear at almost any horizon there is, in general, a reasonably orderly sequence in their appearance and it is this sequence, as well as the rather exceptional types, that characterizes the Franciscan throughout its extent.

Although the base of the Franciscan is not exposed, or at least has never been observed, some of the exposures near the present coast line can not be far above the original base and a reasonably complete sequence may be observed. Whereever a thick section is exposed the same general succession of lithologic types occurs.

The lower part of the Franciscan, throughout its extent in California and Oregon, is chiefly arkosic sandstone. Shale partings occur and in some places there are bodies of shale several hundred feet thick, but the predominant type is arkosic sandstone. In this lower part, which makes up half or more of the Franciscan, there are flows of basalt and lenses of chert, but these do not attain the same thickness or areal extent as higher in the section. Throughout its thickness the sandstone shows definite evidence of having been deposited in shallow water; geosynclinal sinking kept pace with deposition.

After the deposition of many thousands of feet of sandstone, and a corresponding depression of the trough, widespread submarine volcanism began and a variable thickness of basic flows, tuffs, breccias, and agglomerates accumulated.

[48] N. L. Taliaferro, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *Bull. Geol. Soc. America* (in press).

The maximum development of radiolarian cherts coincided with, and immediately followed, maximum volcanism. Maximum volcanism neither began nor ended at the same time everywhere nor was it universal in the entire basin of deposition. There are thick sections of the Franciscan in which volcanics and cherts are scarce or even lacking, the predominant rocks being coarse to fine clastics. In some regions volcanism continued much longer than in others; this seems to be especially true of a part of the region south of San Francisco Bay where, in at least one locality, volcanism continued to, or almost to, the close of the Jurassic, and volcanics and cherts are found interbedded with typical Knoxville shales containing late Upper Jurassic fossils.

The deposition of sands, silts, and gravels continued during the outpouring of submarine volcanics and the volcanics and cherts are interbedded with sandstones, shales, and gravels. The relative proportion of clastics, volcanics, and chemical sediments depends on the local intensity of volcanism. The influx of sediments continued after volcanism ceased in some localities and in places there are thick sections of shales and sandstones above the volcanics. By the time volcanism was on the wane in most regions, a great thickness, more than 10,000 feet, of sediments and volcanics had accumulated, the high and rugged land mass from which the arkosic sandstones were derived had been greatly lowered, and chemical decomposition became more important with the wearing-down of the land and the lessening of stream velocity. This resulted in a greater proportion of dark sandy and clay shales which predominate in the upper part of the Franciscan and which constitute the phase known as the Knoxville.

The various lithologic types making up the Franciscan are described. The descriptions of the various types, with the exception of the sandstones and schists, are brief as a more complete account of these rocks will be given in a future paper. The sandstones, which constitute the great bulk of the Franciscan, are described in detail as they give important information regarding the source of the detritus, the nature and climatic conditions of the highlands from which they were derived, and the conditions of deposition.

The field occurrence of the schists and their general nature are described rather fully since many of the erroneous ideas regarding the extent of metamorphism and subsequent history of the Franciscan are the result of misinterpretations of the origin of these rocks.

SANDSTONE

Arkosic sandstone is the predominant rock type in the Franciscan and, in any reasonably complete section makes up half to more than three-quarters of the total thickness. It is possible to give only approximate figures of the percentage of sandstone, but it is certain that this type is more abundant than all other rock types combined when the total thickness and areal extent are considered. In the San Francisco Bay region Lawson[49] reports approximately 5,000 feet of sand-

[49] A. C. Lawson, "San Francisco, California," *U. S. Geol. Survey Geol. Atlas Folio 193* (1914).

stone, 1,430 feet of chert, and 60 feet of limestone; thus, in this region sandstone makes up more than 75 per cent of the total sediments. These figures, however, are only approximate and it is possible that sandstones make up a greater proportion. The thickness of the cherts has been overestimated; two main chert formations are reported although actually there is only one thick formation and innumerable small scattered lenses.

In the Panoche Pass section, in central San Benito County, there are comparatively few volcanics and cherts, and the Franciscan is chiefly massive sandstone and thin-bedded sandstone and shale. Northward along the east side of the Diablo Range, volcanics and cherts are much more abundant, but even where most abundant sandstones make up more than 75 per cent of the Franciscan.

The sandstones have been described by Davis[50] who gave an excellent account of the minerals present and presented two chemical analyses. He believed the sandstones to be, in large part, continental, deposited under arid conditions on the piedmont slope of a land mass made up of granodiorites and crystalline schists. Reed[51] questioned the theory of continental origin and pointed out the fact that the sandstone is in many places interbedded with marine sediments. One of Davis' arguments in favor of a continental origin, the presence of angular chips of shale, is not valid since fossiliferous Knoxville and Lower Cretaceous sandstones contain abundant identical shale fragments.

The writer believes that the arkosic sandstone of the Franciscan was deposited in shallow marine waters in a slowly sinking basin. Depression of the basin kept pace with deposition except on the margin, which was occasionally slightly disturbed and uplifted, resulting in the erosion of the earlier sediments. In the hundreds of sections studied by the writer, the sandstones are remarkably uniform and those that are interbedded with radiolarian cherts and foraminiferal limestones are identical with the sandstones as a whole. Furthermore indeterminate marine fossils occur in the sandstones; also, the sandstones are interbedded with dark sandy shales that contain small lenses of dark impure limestones containing scattered foraminifera.

The sandstones of the Franciscan, from Santa Barbara County northward through the California Coast Ranges and into Oregon, are characterized by general angularity of grain and an abundance of fresh plagioclase feldspar. Although there are local variations, such as a great increase in the proportion of rock fragments, especially shale flakes, and in the ratio of quartz to feldspar, the sandstone is without exception feldspathic and the grains are angular to subangular.

Carbonized plant remains are abundant in both the sandstones and silts and in places are so numerous as to form thin seams of impure coal. All this material is greatly fragmented and macerated, indicating transportation for a considerable

[50] E. F. Davis, "The Franciscan Sandstone," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11 (1918), pp. 1–44.

[51] R. D. Reed, *The Geology of California*, Amer. Assoc. Petrol. Geol. (1933).

distance. The thin impure coaly layers do not represent plant growth in place but simply a local concentration of carbonized plant remains washed into the basin of deposition; the impure coals are entirely allochthonous. The abundance of carbonized wood fragments indicates that at least a part of the area from which the detritus was derived was well wooded.

Mineral analyses of the sandstones have been made by graduate students in the University of California in the past 10 years and the writer has examined thin sections of more than 100 sandstones from San Luis Obispo County northward to Oregon. These studies indicate that there are certain regional variations in the quartz-feldspar ratio but they are not as yet sufficiently detailed to warrant any positive statement. The mineral and chemical analyses that have been made and a summary of the results obtained are presented. This should be regarded as a preliminary progress report only; regional studies are in progress and future reports of the results will be issued.

Thus far only fresh, little altered, and veined sandstones have been studied in detail. Care has been taken to collect fresh, unweathered, and unaltered sandstones from artifical road and tunnel cuts and from natural stream cuts. A study of the various types of altered sandstones is a separate problem.

Before discussing the lithology, the various types of alteration suffered by the sandstones are briefly mentioned since one of these is universal and can not be ignored in a discussion of the lithology; the others are of importance to a general understanding of the subsequent history of the Franciscan as a whole. The various types of alteration may be outlined as follows.

1. Changes due to deep burial and folding. This type of change is universal and, where uncomplicated by actual shearing, has resulted in a modification and crystallization of the ground mass without any notable granulation or recrystallization of the individual grains. Because of the finely divided character of the products little can be said as yet regarding the exact nature of all the minerals formed. In general the intergranular material originally appears to have consisted of finely divided silt, small chips of quartz, feldspar, and other original minerals, and cement, calcareous in a few cases, siliceous in others. The products that can be recognized with certainty are sericite, chlorite, zoisite, calcite, chalcedony, quartz, dark patches of organic substances, and minute granules of magnetite. In many places, this recrystallized interstitial material so firmly binds the rock that, in unweathered outcrops, it breaks across the grains.
2. Changes due to hydrothermal alteration. These changes are numerous and complex and as yet have not been studied in detail. Such changes are not uncommon along fault zones but they are also frequently seen in small to very large irregular areas in the midst of unaltered sediments. It is not uncommon to find unaltered sediments passing in a short distance into zones in which the sandstones are highly altered and veined and the shales decidedly phillitic or even schistose through the development of abundant sericite. Where this type of alteration is combined with shearing the sandstones are decidedly schistose and the individual grains are strongly granulated. Ordinarily, hydrothermal alteration of this type results in the partial or complete destruction of the feldspars into a fine granular aggregate of sericite, zoisite, epidote, clay, quartz, and in places calcite. The feldspar grains lose their sharp outline and merge with the recrystallized interstitial material; the quartz grains are unmodified except by granulation. Quartz and calcite veins are numerous. Ordinary hydrothermal alteration of this type does not appear to result from the contemporaneous flows and intrusions. It appears to be later than the consolidation and folding of the Franciscan; in some places it is clearly related to Tertiary intrusions.
3. Crushing against resistant igneous masses. Where intrusions of basalt, diabase, and peridotite are numerous the sediments were crushed against such bodies during the various periods of disatrophism in the Cretaceous and Tertiary, resulting in shearing and slickensiding. This is combined in places, with hydrothermal action and the sediments are greatly altered. This is more fully discussed under the metamorphism of the Franciscan.

4. Changes due to pneumatolytic contact action. This is a local change on the borders of or near basic and ultrabasic intrusives. This is discussed in connection with the glaucophane and related schists.
5. Changes due to ordinary weathering. This results in the breakdown of the interstitial material and alteration of the feldspar. The bluish green to green color of the fresh sandstone changes to buff, yellow, or brown, due to the oxidation of the iron, and the sandstone becomes soft and friable.

The first of the foregoing changes is the only one that universally takes place and modifies the original mineral composition of the sandstones; effects of the other changes may be avoided by the selection of fresh material. Even this change is not of great importance since the essential minerals are not affected. However, it may be the chief cause of the discrepancy between the chemical and mineral analyses as the method of preparation of fresh sandstones involves crushing and generally the elimination of the recrystallized interstitial material.

TABLE I

MINERAL ANALYSES OF 17 FRANCISCAN SANDSTONES FRON CALIFORNIA COAST RANGES

(Both light and heavy fractions computed to 100 per cent)

	1	*2*	*3*	*4*	*5*	*5*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
Light																	
Quartz	55	35	40	35	50	60	65	60	60	60	65	65	55	65	60	65	60
Orthoclase	5	20	10	20	10												
Microcline					1												
Albite	5	15	10	15	10	35	30	30	30	30	25	25	40	30	30	25	35
Oligoclase	35	20	35	28	25												
Andesine	Pr	Pr	Pr	Pr	2												
Rock fragments	Pr	10	5	2	2	5	5	10	10	10	10	10	5	5	10	10	5
Hea ies	0.14	0.36	0.59	0.44	0.25	2.0	1.7	0.4	0.3	0.9	1.2	0.3					2.3
Magnetite	0.46	3.17	0.87	1.83	1.44	3.8	5.1	3.0	3.9	4.3	10.1	11.0	3.7	9.4	12.1	4.9	8.6
Ilmenite-leucoxene	13.6	15.9	11.6	18.4	14.8	12.2	11.5	15.2	12.1	10.7	4.6	3.7	12.2	3.8	2.0	2.5	11.6
Pyrite	Pr				Pr	4.1	3.4	6.1	1.9	2.1	4.1	1.2	1.3	11.0	1.2	10.3	7.0
Zircon	4.9	5.5	2.9	4.6	10.3	4.9	5.8	6.1	6.1	5.2	5.0	4.9	2.6	1.3	5.8	4.9	4.9
Sphene	3.6	2.5	3.1	3.5	4.2	10.2	11.4	15.2	9.5	10.3	11.3	9.8	10.3	4.1	8.3	11.4	2.3
Pink garnet	2.2	1.6	1.2	1.6	3.4	4.2	3.9	6.1	1.9	1.3	2.0	1.2	1.3	5.4	4.7	3.9	5.6
Rutile	Pr	Pr		Pr	Pr												
Zoisite	Pr			Pr										Pr		Pr	Pr
Clinozoisite				Pr	Pr		Pr	Pr									
Epidote	3.2	1.6	3.2	2.1	3.2	5.1	3.9	21.1	4.6	5.3	7.1	4.9	5.8	5.1	4.2	6.4	2.3
Tourmaline	1.4	0.7	Pr	0.5	Pr	2.0	2.3		3.4	3.0	2.9	3.7	1.4	2.1	1.8	2.0	3.5
Muscovite	Pr	Pr	Pr	Pr	Pr												
Biotite	Pr	Pr	Pr	Pr	Pr				3.0	2.0	3.0	4.0	3.6	4.2	Pr	Pr	Pr
Hornblende	Pr	1.2		Pr	Pr	2.0	3.1		2.8	3.1	3.0	2.4	2.0	6.2	3.3	4.6	2.1
Augite		Pr	Pr		Pr												
Chlorite	Pr	1.0	0.5	1.0	Pr	3.0	4.1	3.0	5.1	4.9	6.1	7.3	4.1	7.4	3.0	5.8	1.9
Rock fragments	69.9	69.3	76.7	67.7	64.1	48.1	45.4	24.2	45.7	47.7	34.9	46.0	53.4	41.2	53.2	44.4	48.0

Mineral analyses 1 to 5, inclusive, are from a doctor's dissertation by F. A. Johnson, "Geology of the Merced, Pliocene Formation North of San Francisco Bay, California," 1934—General Library, University of California.

Analyses 6 to 12, inclusive, are from an unpublished master's thesis by E. F. Dosch, "The Las Tables Fault Zone and Associated Rocks," 1932—General Library, University of California.

Analyses 13 to 17, inclusive, are from an unpublished master's thesis by C. L. Goudy, "A Structural and Petrographic Study of the Vaqueros and Associated Formations in the Southeast Portion of the Adelaida Quadrangle, California," 1936—General Library, University of California.

Location of sandstones:

1, 2, 3, 4, 5, Johnson. Specific localities not given. All are of fine- to medium-grained sandstones north of San Francisco Bay in the Sebastopol and Duncans Mills (War Department) quadrangles and in the northern part of the Point Reys and Petaluma quadrangles. This region is 35–60 miles northwest of San Francisco.

6, 7, Dosch. Coarse Franciscan sandstone, branch of Las Tables Creek, near line between Secs. 32 and 33, T. 26 S., R. 10 E., Adelaida Quadrangle.

8, Dosch. Fine-grained Franciscan sandstone, south of Klau quicksilver mine, Sec. 33, T. 26 S., R. 10 E., Adelaida Quadrangle.

9, 10, Dosch. Fine-grained Franciscan sandstone, south of Carroll Creek, Sec. 17, T. 26 S., R. 9 E., San Simeon Quadrangle.

11, 12, Dosch. Fine-grained Franciscan sandstone, northeast corner of Sec. 27, T. 26 S., R. 9 E., Adelaida Quadrangle.

13, Goudy. Medium-grained Franciscan sandstone, Sec. 31, T. 27 S., R. 11 E., Adelaida Quadrangle.

14, Goudy. Medium-grained Franciscan sandstone, Sec. 26, T. 27 S., R. 10 E., Adelaida Quadrangle.

15, Goudy. Medium-grained Franciscan sandstone, Sec. 18, T. 27 S., R. 11 E., Adelaida Quadrangle.

16, Goudy. Medium- to coarse-grained Franciscan sandstone, Sec. 13, T. 27 S., R. 10 E., Adelaida Quadrangle.

17, Goudy. Medium-grained Franciscan sandstone, Sec. 13, T. 27 S., R. 10 E., Adelaida Quadrangle.

Table I lists the minerals present in 17 fresh unweathered Franciscan sandstones from the Coast Ranges of California, the percentages being based on actual mineral counts. Because of the resistance of the recrystallized cement it is nec-

essary to crush the samples, boil in potassium hydroxide, wash, boil in dilute hydrochloric acid, and then again crush as gently as possible. Frequently, it is necessary to repeat the process before making the bromoform separations. Certain of the original minerals and the minerals developed by crystallization of the interstitial material are partly or completely destroyed by this process. Apatite is completely lost and biotite and chlorite partly destroyed. Because of the difficulty in breaking down the samples, not all mineral analyses of the Franciscan sandstones are reliable. Mechanical analyses are of little value in showing the size ranges because of the unavoidable crushing.

TABLE II

AVERAGE MINERAL CONTENT OF FRANCISCAN SANDSTONES

Mineral	*Average of 5. N. of San Francisco Bay*	*Average of 12. Southern Santa Lucia Range*	*Average of all 17.*
Light			
Quartz	43.2	61.7	56.2
Feldspar	53.0	30.4	37.1
Rock fragments and composite grains	3.8	7.9	6.7
Heavies	0.36	1	1
Magnetite	1.5	6.6	5.1
Ilmenite-leucoxene	14.7	7.8	9.8
Pyrite	Tr.	4.4	3.1
Zircon	5.6	4.8	5.0
Sphene	3.4	9.5	7.7
Garnet	2.0	3.4	3.0
Epidote	2.7	6.2	5.2
Tourmaline	0.6	2.3	1.8
Biotite	Pr.	1.7	1.2
Hornblende	Pr.	2.8	2.0
Chlorite	0.6	4.8	3.5
Rock fragments and composite grains	68.5	45.3	51.8

The mineral analyses shown in Table I are not sufficiently numerous or widely distributed to justify a positive statement about any broad regional variation, but taken in conjunction with the chemical analyses and the study of many thin sections they indicate an increase in quartz and corresponding decrease in feldspar southward from the northern Coast Ranges. This increase is also indicated by an examination of more than 100 thin sections. There also appears to be a southward increase in sphene, epidote, tourmaline, and biotite; this increase has not been checked by other observations. Not all of the sandstones in the Coast Ranges south of San Francisco Bay show a higher percentage of quartz; in some phases feldspar predominates.

The first five mineral analyses are from the area north of San Francisco Bay between Petaluma and the mouth of the Russian River and the last 12 from the Adelaida and Simeon quadrangles approximately 225 miles south. Because of the rather considerable difference in the amount of feldspars present in these two general areas, separate averages have been made. These are shown in Table II. Before discussing these averages the chemical analyses are presented and calculated on various systems.

There are comparatively few chemical analyses of Franciscan sandstones given in published reports, three only having been found. A new analysis, made for the writer in the Herdsman Laboratory, Glasgow, is given. These analyses, together with composite analyses of a large number of ordinary sandstones for comparison, are given in Table III.

TABLE III

ANALYSES OF FRANCISCAN SANDSTONES WITH TWO ANALYSES OF AVERAGE SANDSTONES FOR COMPARISON

	I	II	III	IV	IVa	V	VI
SiO_2	68.84	68.50	71.72	56.84	67.58	78.66	84.86
TiO_2	0.25	0.60	0.35	nd		0.25	0.41
Al_2O_3	14.54	12.82	13.23	11.37	13.47	4.78	5.96
Fe_2O_3	0.62	1.29	.30	1.46	1.75	1.08	1.39
FeO	2.47	3.37	3.58	4.95	5.98	.30	.84
CaO	2.23	1.82	1.80	7.62	3.95	5.52	1.05
BaO	0.04	nd	nd	nd		0.05	0.01
MgO	1.94	2.21	1.81	3.10	1.88	1.17	0.52
K_2O	2.68	1.26	1.29	0.86	1.05	1.32	1.16
Na_2O	3.88	6.03	2.72	3.26	3.95	0.45	0.76
ZrO_2	0.05	nd	0.04	nd		—	—
H_2O-	0.35	0.28	0.15	1.45		0.31	0.27
H_2O+	1.60	2.11	2.53	3.24		1.33	1.47
CO_2	0.14	nd	0.32	5.10		5.04	1.01
P_2O_5	0.15	0.16	0.09	0.10	0.12	0.08	0.06
SO_3	0.15	nd	nd	nd		0.07	0.09
MnO	nil	0.02	nil	0.22	0.27	—	—
	99.93	100.47	99.93	99.67	100.00	100.41	99.86

nd indicates the oxide was not determined.
nil indicates not present.
— indicates not reported.

I. Fresh specimen of typical Franciscan sandstone from the quarry of the Oakland Paving Company, Piedmont. James W. Howson, analyst. From E. F. Davis, "The Franciscan Sandstone," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11, No. 1 (1918), pp. 22.

II. Franciscan sandstone from Sulphur Bank, California. From G. F. Becker, "Geology of the Quicksilver Deposits of the Pacific Slope," *U. S. Geol. Survey Mon. 13* (1888), p. 92.

III. Fresh Franciscan sandstone from junction of Buckeye Gulch with Hospital Canyon, Carbona Quadrangle, Stanislaus County. Weight of original sample, 24 pounds. Analysis made for the writer by Herdsman, Glasgow.

IV. "Neocomian sandstone; from head waters of Bagley Creek; hard granular and greenish." "The Geology of Mount Diablo, California," H. W. Turner, with "a Supplement on the Chemistry of the Mount Diablo Rocks," by W. H. Melville, *Geol. Soc. America*, Vol. 2 (1891), p. 411. From its geographic position and from Turner's statement that this sandstone came from the "metamorphic area" this is clearly an altered Franciscan sandstone as the Franciscan was called "Neocomian metamorphics" by Turner at that time.

IVa. Same as IV but recalculated, using CaO and MgO (3 to 1) combined with the CO_2 and omitting H_2O. This is evidently an altered sandstone, probably veined with the common calcium-magnesium carbonate veins. When thus recalculated this agrees closely with the other analyses of Franciscan sandstones.

V. Composite of 253 sandstones.

VI. Composite of 371 sandstones used for building purposes. Both composite analyses from F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 770.*

It is obvious from Table III that the chemical composition of the four Franciscan sandstones departs considerably from the composition of the average sandstone, the chief difference being in the silica, alumina, and soda. The low silica and high alumina and soda in the Franciscan sandstones indicate, of course, a comparatively high plagioclase feldspar content, as shown by the first five mineral analyses.

Even a casual inspection of the analyses of the Franciscan sandstones shows that they closely approach the chemical composition of granodiorite. In order to bring out this relationship more clearly some of the analyses have been calculated

according to the C.I.P.W.[52] and Osann[53] systems of igneous rock classification.

Table IV gives the results of these calculations for sandstones I, II, and III of Table III according to the C.I.P.W. system of classification. The composite analyses of many sandstones can not be calculated according to this system as they depart radically from the composition of any igneous rock.

TABLE IV

CLASSIFICATION OF FRANCISCAN SANDSTONES I, II, AND III OF TABLE III
ACCORDING TO C.I.P.W. IGNEOUS ROCK CLASSIFICATION

	I *Norm*	*II* *Norm*	*III* *Norm*
Quartz	26.40	21.72	42.00
Orthoclase	16.12	7.78	7.78
Albite	33.01	50.83	23.06
Anorthite	11.12	3.89	8.26
Corundum	1.02	—	4.25
Hypersthene	8.36	7.90	10.31
Diopside	—	3.43	—
Ilmenite	0.61	1.22	0.61
Magnetite	0.93	1.86	0.46
Apatite	0.31	0.31	0.34
Zircon	0.12	—	0.09
	I: Persalane	II. Dosalane	I. Persalane
	4. Britannare	4. Austrare	3. Columbare
	2. Toscanase	3. Dacase	2. Alsbachase
	4. Lassenose	4. Dacose	4. Tehamose
	Symbol: I.4.2.4	Symbol: II.4.2.4	Symbol: I.3.2.4

From the results shown in Table IV it is seen that sandstones I and II fall between granodiorite and quartz diorite and III between granodiorite and granite. The minerals listed are, of course, "normative" or standard minerals used in the classification and are not necessarily present. The corundum in I and III is due to an excess of alumina over the alkalies and may represent original clayey material in the groundmass; corundum is not an uncommon normative mineral in certain igneous rocks although very rare in the mode.

The following results were obtained by using Osann's system.

Franciscan sandstone I.
S:Al:F=24:3:3
Al:C:Alk=15.4.5:10.5
Rock formula: $^{s}75.82\ ^{a}12\ ^{c}6.5\ ^{f}11.5\ ^{n}6.8$
Both the S:Al:F and the Al:C:Alk ratios fall well within the igneous rock fields on the Osann diagrams. On the S:Al:F diagram this sandstone falls between granite and quartz diorite and corresponds in chemical composition with granodiorite.

Franciscan sandstone II.
S:Al:F=24:2.5:3.5
Al:C:Alk=14:3.5:12.5
Rock formula: $^{s}74.72\ ^{a}12.5\ ^{c}2\ ^{f}11\ ^{n}8.7$
Both the S:Al:F and the Al:C:Alk ratios fall well within the igneous rock fields on the Osann diagrams and the sandstone corresponds with granodiorite.

[52] H. S. Washington, "Chemical Analyses of Igneous Rocks Published from 1884 to 1913 inclusive, with a Critical Discussion of the Character and Use of Analyses," *U. S. Geol. Survey Prof. Paper 99* (1917), pp. 1151–65.

[53] A. Osann, *Elemente der Gesteinlehre.* Stuttgart (1922).

Franciscan sandstone III.
S:Al:F=24:3:3
Al:C:Alk=17:5:8
Rock formula: $^{s}79.05\ ^{a}9.20\ ^{c}11.27\ ^{f}9.53\ ^{n}7.59$
This sandstone falls well within the igneous rock fields; on the S:Al:F diagram it is between granite and quartz diorite.

Sandstone V.
Average of 253 ordinary sandstones. The presence of 5.04 per cent of CO_2 in this composite analysis indicates a $CaCO_3$ cement. Using the lime and part of the magnesia combined with the CO_2 and recalculating to 100 per cent, the following results were obtained on the Osann system:
S:Al:F=29:1:0
Al:C:Alk=6.7:8.3:15
Rock formula: $^{s}79.05\ ^{a}13.38\ ^{c}16.62\ ^{f}0\ ^{n}3.28$
This sandstone falls outside all the Osann igneous rock diagrams. While a perfectly normal sandstone it does not correspond in composition with any normal igneous rock.

It is believed that the results of these calculations are interesting and show clearly that the available chemical analyses of Franciscan arkosic sandstones correspond, even in detail, with granodiorite.

Analyses I, II, III, and IV are of sandstones in the vicinity of San Francisco Bay and in the northern Coast Ranges; these have a silica percentage more in harmony with the high feldspar content of the first five mineral analyses of Table I than with the twelve mineral analyses from the southern part of the Santa Lucia Range, 200 miles south. No chemical analyses of Franciscan sandstones in the central Coast Ranges, in the vicinity of the last twelve mineral analyses of Table I, are available.

However, there is a descrepancy between even the five northern California mineral analyses and the chemical analyses. As shown in Table II, the average quartz and feldspar content of the five analyses are 43.2 and 53.0, respectively. If the silica and alumina percentages of this average are calculated on the basis of orthoclase 12 per cent, albite 12 per cent, and oligoclase 29 per cent (averages from Table I), and the rock fragments (3.8 per cent) are considered to be 50 per cent silica and 15 per cent alumina, the silica percentage is 78.7 and the alumina is 12.03. Thus, the computed silica percentage is almost 10 per cent higher than the average of the four chemical analyses and the alumina slightly lower. If it is assumed that the chemical analyses represent a fair average for the region, it is obvious that there must be some error either in the mineral analyses or in the method of treating the sandstone prior to the analyses. It is believed that the method of boiling the crushed sandstone in acid, in order to loosen the grains for separation and study, destroys some of the material originally present, probably some of the interstitial material. It is believed that in every case the percentage of quartz indicated is too high. It is not believed that the average quartz content of the Franciscan sandstones as a whole is as high as 56 per cent, as indicated by Table II, but that the average, at least north of San Francisco Bay, is less than 50 per cent, and possibly less than 45 per cent. The feldspars are higher, above 50 per cent.

However, it is clear from both the chemical and mineral analyses, as well as

from a study of thin sections, that the Franciscan is highly feldspathic and that the most abundant feldspar is acid plagioclase. Also it is clear that the sandstone was derived from crystalline rocks having the general composition of granodiorite. The composition of the heavies is consistent with such an origin.

It is impossible as yet to make any possible statement regarding quartz-feldspar ratio or its regional variation. However, from the mineral analyses and the examination of more than 100 thin sections, there appears to be an increase in quartz and a decrease in feldspar southward from San Francisco Bay, at least as far as San Luis Obispo County. It is not believed that this indicates any difference in weathering at the source or in transportation, but that it may reflect a real difference in the composition of the rocks of the land mass supplying the detritus. This difference might be due to a greater proportion of schists and quartzites at the south (not reflected, however, in the character of the heavies, which is reasonably constant), or to a somewhat more acidic plutonic rock. It will be necessary to have many more chemical and mineral analyses before this question can be answered.

Aside from a possible increase in quartz southward, the average unaltered Franciscan sandstone is remarkably uniform throughout the California and Oregon Coast Ranges. It is characterized by a quartz-feldspar ratio that, on the average, varies from 2:3 to 3:2, by the great predominance of an acid plagioclase (oligoclase), by the freshness of the feldspar, by angularity of grain, and by the chemical composition of granodiorite. All of these facts indicate that mechanical disintegration predominated over chemical decomposition in the area from which sandstone was derived. This could be due either to an arid climate or to heavy rainfall and a high rugged land mass. The great abundance of carbonized wood fragments and here and there very thin coaly layers does not favor the theory of an arid climate. The amount of carbonized wood in the Franciscan indicates derivation from a terrane whose lower slopes at least were well wooded and consequently well watered. The great thickness of the sandstone in a wide area and its deposition in a comparatively small part of the Upper Jurassic indicate rapid deposition and great floods of detritus. Its width of outcrop, from the Great Valley to the Pacific Coast (originally greater than at present because of shortening of the region by diastrophism), and its uniform character over this width indicate rather large rivers, which is not consistent with the idea of aridity.

The writer believes that all of the available evidence indicates that the Franciscan was derived from a high, rugged, recently uplifted land mass under rigorous climatic conditions, high rainfall, and possibly a cold climate in the highlands with well wooded lower slopes. The rivers from this area were large and of high gradient and brought down great floods of unaltered detritus into a shallow sinking basin. The land mass from which the greater part of the Franciscan detritus was derived was made up of granodiorite, crystalline schists, quartzites, recrystallized black cherts, and numerous intrusions of quartz and feldspar porphyries. The location of the source is considered in a later section.

SHALES

The shales of the Franciscan have not been studied in any great detail. Nearly all are dark-colored and vary from comparatively coarse silts to fine clay shales; silts are more abundant than clay shales. Organic black shales occur here and there in northern California, especially along the coast south of Eureka, where there are a few seepages of oil; a very small quantity of light oil has been produced from the Franciscan in the Petrolia district in Humboldt County. Calcareous clay shales occur and impure dark limestone lenses are not uncommon. In many places the shales are slightly slaty, because of the depth of burial. Many of the shales interbedded with the cherts are either red or green, according to the state of oxidation of the iron present.

The ordinary silts and clay shales are interbedded with sandstones, but in places there are sections a few hundred feet thick in which silts predominate. Carbonized plant remains are abundant in the shales but they are too small and fragmentary to be of any value in determining the age. The fragmental condition of the plant remains indicates that they were deposited a considerable distance from the source.

The shale beds in the sandstones of the lower part are, as a rule, thin and widely scattered but they become more abundant in the upper part of the Franciscan; where unsheared, they are identical with the Knoxville shales. Where both the Franciscan and Knoxville have been greatly compressed and sheared, as commonly found near the crest of the Santa Lucia Range, the slaty shales in each are lithologically identical.

A few of the shales have been examined under the microscope, by use of an oil immersion objective but the work has been too limited to make any positive statement regarding the various types. However, all that have been studied contain a large proportion of very angular mineral fragments. In some, quartz predominates over plagioclase, but in others they appear to be present in about equal amounts. Mineral grains make up half to more than 80 per cent of the shales examined. Magnetite, sericite, chlorite, earthy iron oxide, epidote, and spinel (?) are also present; any original clayey material present ordinarily has been crystallized to a dense aggregate. In some places, radiolaria and foraminifera are present. The grains range from 0.002 to 0.02 millimeter in diameter.

Next to the sandstones, shales are the most plentiful sediments in the Franciscan, although there are some sections in which cherts are as abundant as the shales.

CONGLOMERATES

Conglomerates are neither thick nor plentiful in the Franciscan but they are rather widely distributed, both geographically and stratigraphically, as comparatively thin lenses. Ordinarily the pebbles are small, an inch or less in diameter, but some attain cobble and even boulder size. The conglomerates are coarser and more abundant in the western part of the central Coast Ranges, indicating a western source for the material.

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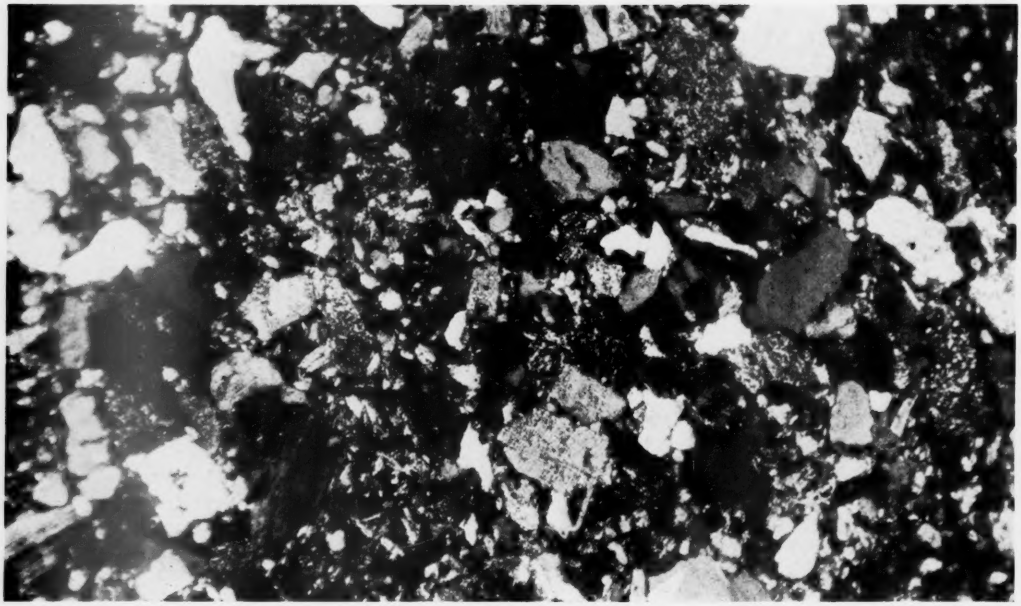
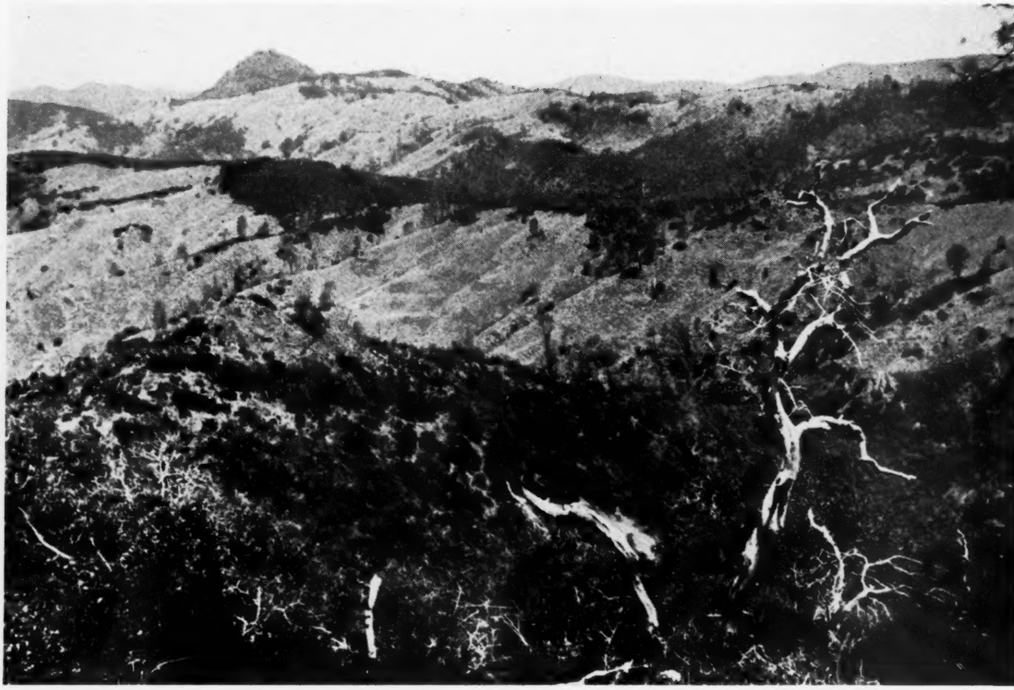
TALIAFERRO PLATES I–VII



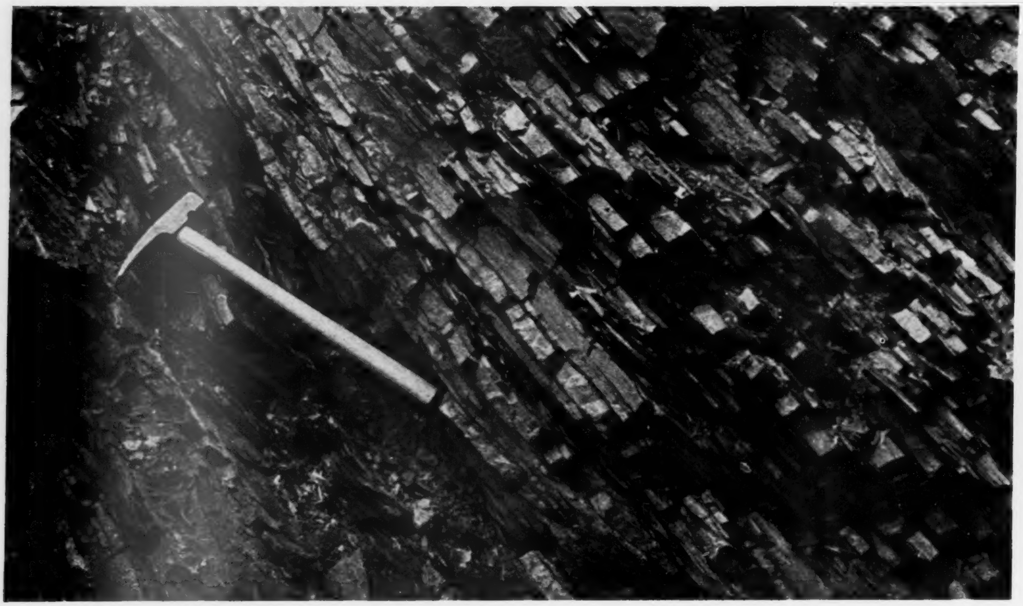
A. Franciscan sandstone. Near crest of Santa Lucia Range. Center, SW. ¼ Sec. 20, T. 26 S., R. 9 E., San Simeon Quadrangle, San Luis Obispo County, California. ×50. Crossed nicols.

B. Franciscan sandstone. East bank of Eel River, 17 miles south of Garberville, Mendocino County, California. ×50. Crossed nicols.



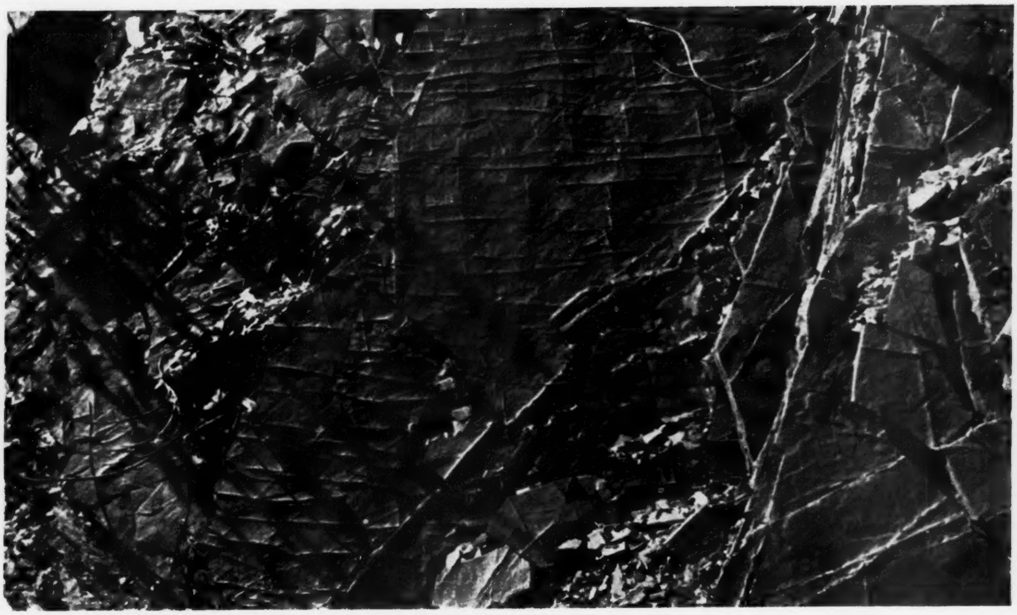
A. Looking north toward Burnett Peak (elevation, 3,025 feet), crest of Santa Lucia Range, San Simeon and Bryson quadrangles, northern San Luis Obispo County, California. Entire area shown is underlain by Franciscan. Burnett Peak is basalt-diabase plug.

B. Looking east toward Alder Peak (elevation, 3,747 feet), on crest of Santa Lucia Range, Cape San Martin Quadrangle, southern Monterey County, California. Entire area underlain by Franciscan. Typical of scenery in this part of range.



A. Thin-bedded Franciscan chert and shale, on trail to Buckeye manganese mine south side of Buckeye gulch, Carbona Quadrangle, Stanislaus County, near San Joaquin County line, California. Hammer is 18 inches in length.

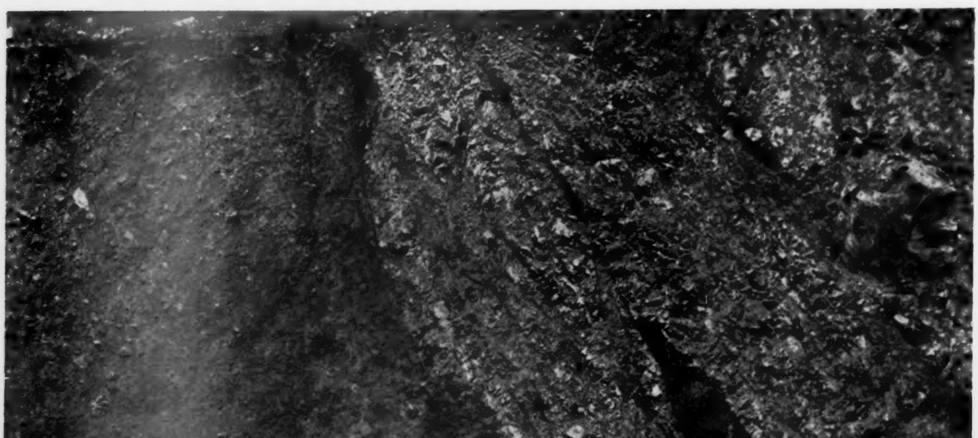
B. Contorted Franciscan chert and shale enclosed in sandstone. On ridge above Buckeye manganese mine. Ichthyosaur rostra described by Camp came from chert boulders derived from similar radiolarian cherts.



A. Bedding surfaces of thin-bedded red radiolarian chert showing pattern of innumerable thin quartz veins. Carbona Quadrangle, on line between Stanislaus and San Joaquin counties, California.

B. Well bedded Franciscan sandstone and shale, on Hollister-Panoche road. Western edge of Panoche Quadrangle, San Benito County, California. Hammer is 18 inches in length.

A. Serpentine (right) intrusive into Knoxville shales (left). Road cut, Middletown-Lower Lake Highway, 4 miles north of Middletown, Lake County, California. Photo by Olaf P. Jenkins.



B. Detail of contact shown in A. Notice included lens of shale in serpentine at right of contact. Photo by Olaf P. Jenkins.

A Franciscan limestone with thin interbeds of red radiolarian chert. Part of limestone lens 500 feet long, inclosed in typical Franciscan arkosic sandstone and basalt. Just east of Redwood Highway, 2 miles north of Laytonville, Mendocino County, California. Photo by Olaf P. Jenkins.

B. Looking east toward Impassable Rock (elevation, 5,900 feet), Sanhedrin Ridge, Eden Valley Quadrangle, southern Mendocino County, California. Entire area shown is made up of Franciscan sandstone, chert, and basalt.

A. Looking northwest from crest of Santa Lucia Range in San Simeon Quadrangle (northern San Luis Obispo County) across Bryson Quadrangle (southern Monterey County). Light-colored barren areas in middle ground are Franciscan rocks thrust northeastward over Upper Cretaceous sediments (dark brushy areas). Valley of San Antonio River in right middle ground. High peak on skyline on left is Junipero Serra Peak; elevation, 5,844 feet, 40 miles distant.

B. Looking south-southeast along precipitous coast line in southern Monterey and northern San Luis Obispo counties. Piedras Blancas Point, 17 miles distant, is partly obscured by clouds. Taken from San Martin Top; elevation, 2,825 feet, Cape San Martin Quadrangle. Entire area made up of Franciscan sediments and volcanics, dipping northeast.

Although observations have been made on Franciscan conglomerates throughout the Coast Ranges, they have not been as carefully studied as the sandstones. However, it is known that, like the sandstones, there is a remarkable similarity in the constituents.

The commonest pebbles and boulders are various types of porphyries, quartzites, recrystallized cherts, old volcanic rocks, granodiorite, granite, and Franciscan rocks. Recrystallized limestones, schists, vein quartz, and sheared grits and conglomerates are less common. Probably the most abundant types are porphyries, quartzite, and recrystallized black chert. These are also the commonest pebbles in the Knoxville conglomerates.

Several types of porphyritic rocks occur; ordinarily these have dense to very fine-grained recrystallized groundmasses. Quartz porphyries, feldspar porphyries, plagiosclase quartz porphyries, and plagioclase porphyries are abundant. These are gray, black, purple, green, and red in color, and nearly all are well rounded. Thoroughly recrystallized gray, black, and red quartzites are common as well rounded to subangular pebbles. The dense recrystallized black and gray cherts are totally unlike the Franciscan cherts and represent much older rocks. Pebbles of this type also are common in the older Mariposa beds of the Sierra Nevada and probably came from the same source. Flow-banded recrystallized rhyolites are not uncommon as pebbles and cobbles. Gray and black recrystallized limestones and marbles are present, but not plentiful. Cobbles and boulders of granodiorite, granite, and quartz diorite are commonly present, especially in the western part of the central Coast Ranges; they are not common in the conglomerates in northern California. Flattened amphibole-chlorite schist and quartz-mica schist pebbles are scarce except in the northern Coast Ranges. Milky vein quartz and chalcedony pebbles are nearly everywhere present in small numbers. Pyrite and chalcopyrite are commonly present in the quartzite, black chert, and quartz pebbles.

All of the older metamorphic and igneous constituents are well rounded as a rule, which is in marked contrast to the angularity of the sandstone grains; even the sand grains forming the matrix of the conglomerates are angular.

The coarsest conglomerates seen by the writer occur near the crest of the Santa Lucia Range, on the crest trail, in the San Simeon Quadrangle. The ordinary types of pebbles are present but there is an exceptionally large proportion of boulders of quartz-rich, ferromagnesian-poor granites and granodiorites. The maximum diameter of the boulders is 16 inches and the average is about 5 inches. Little or no Franciscan débris is present in this region.

Franciscan débris is rather common in the conglomerates, but it is not universally present. Practically all of the rock types found in the Franciscan are represented but sandstones and shales are the most abundant. Ordinarily the Franciscan débris is angular to subangular, but moderately well rounded pebbles and cobbles occur. The comparative abundance of Franciscan types in the conglomerates has been taken as evidence of marked unconformities within the

Franciscan, but this is not necessarily true; it is not a phenomenon peculiar to the Franciscan as Cretaceous and even Tertiary conglomerates contain débris of the rocks with which they are interbedded. It must be remembered that the Franciscan was deposited in shallow water and that exceptional floods would channel and erode the previously deposited sediments; uplift and folding are not necessary to account for much of the Franciscan material in the conglomerates.

It is clear in some places that the Franciscan débris is due to channeling of the underlying beds without uplift; in other places actual uplift appears to have occurred. This is best illustrated by actual examples. In the southeastern part of the San Lorenzo Grant, Priest Valley Quadrangle, cherts and basalts are interbedded with sandstones and shales. In one place the sandstone, which is medium- to coarse-grained, contains numerous angular blocks of green and red chert. The blocks are flat and some are as large as 18 inches across; the thickness is the same as that of the individual chert layers, 2–4 inches. They ordinarily have sharp angular corners but some are slightly rounded. Angular shale flakes also are abundant. The chert breccia is interbedded with ordinary sandstones, shales, and rhythmically bedded green and red cherts, and there is no discordance in attitudes in the section. The chert breccia is evidently intraformational and the result of the break-up of a newly formed chert layer by submarine slumping caused by an earthquake or simply by a sudden influx of a current-borne sand which scoured an underlying chert and incorporated the fragments. The fact that the disrupted chert layer was sufficiently consolidated to break into angular fragments is not an indication that it had been formed for any length of time before disruption. The rapidity of formation and hardening of chert layers has been discussed previously by the writer.[54,55]

Conglomerates and sandstones are interbedded with cherts on the slopes and summit of Mount Oso, in the northern part of the Diablo Range, in Stanislaus County. Angular to subrounded pebbles of Franciscan chert occur in the conglomerates in addition to the ordinary well rounded older metamorphic and igneous rocks. There are scores of exceptionally well exposed beds of chert interbedded with sandstone and conglomerate; all of the beds are perfectly conformable. In neither of the cases cited is there any indication of uplift nor is there any necessity to postulate an uplift to account for the chert débris.

A different type of conglomerate occurs on San Carpoforo Creek, Cape San Martin Quadrangle, 3 miles northwest of the coast. Between the coast and the conglomerate there is a very thick section of typical Franciscan sandstones with few lenses of chert and basalt. The conglomerate, which is local and can not be traced for any distance, is largely made up of angular to subangular blocks of Franciscan sandstone with minor amounts of shale and basalt; a few well rounded pebbles and cobbles of porphyry and quartzite occur. The maximum diameter

[54] N. L. Taliaferro, "The Relation of Volcanism to Diatomaceous and Associated Siliceous Sediments," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 23, No. 1 (1933), p. 50.

[55] *Idem*, "Contraction Phenomena in Cherts," *Bull. Geol. Soc. America*, Vol. 45 (1933), pp. 201–02.

of the débris is 8 inches, but the average is about 1 inch. This conglomerate is overlain by sandstones and shales, similar to those below, and numerous flows of basalt and lenses of chert; there is no angular discordance in the section. This conglomerate coincides with the beginning of maximum volcanism and may have resulted from a slight uplift caused by volcanic action.

The writer does not intend to imply that uplifts did not occur during the deposition of the Franciscan or that Franciscan rocks were not eroded and carried into the basin of deposition. The presence of fairly well rounded Franciscan types indicates that disturbances did occur. However, it is necessary to point out that there are many instances of abundant Franciscan débris in the conglomerates that are susceptible of other interpretations.

No angular discordances have been found in the Franciscan; channeling, such as that reported by Trask,[56] occurs but it is not an indication of uplift, but simply a consequence of shallow-water deposition. Any uplifts that occurred apparently took place outside of the present exposures of the Franciscan, probably on the margins of the basin of deposition. Local unconformities may be found by future work, but there is no evidence that there was any universal widespread uplift during the deposition of the Franciscan.

Glaucophane schist pebbles are found in Franciscan conglomerates but these, even if they were derived from the Franciscan, are not necessarily indicative of strong uplift and deep erosion. As shown later, these schists are not the products of dynamic metamorphism, found at great depths, but are pneumatolytic contact effects that could have been formed at very shallow depths. It is, of course, possible that these schists might have been derived from a pre-Franciscan series such as the Catalina metamorphics.

The writer has studied many sections in the Sierra Nevada and is familiar with the rock types exposed. He can state positively that the pebbles in the Franciscan conglomerates more closely resemble the crystalline rocks now exposed in the Coast Ranges (Sur schists, Santa Lucia granodiorite, Salmon and Abrams schists) than they do the crystalline rocks of the bedrock series of the Sierra Nevada.

The writer believes that the conglomerates supply important information regarding the source and location as well as the rock types exposed. The conglomerates have a coarser texture westward, indicating that the land mass from which most of the detritus was derived lay in that direction. This is borne out by the general absence of débris of Sierran origin.

LIMESTONES

Limestones are fairly common but only rarely do they attain any considerable thickness; ordinarily they are small lenses only a few feet thick. In many places they are foraminiferal but the crystallization of the limestones due to the depth

[56] Parker D. Trask, "Geology of the Point Sur Quadrangle, California," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 16 (1926), pp. 136–41.

of burial and folding makes specific and even generic determination difficult if not impossible. Thoroughly recrystallized indeterminate mollusks occur in places and echinoid spines (?) and calcareous algae are abundant locally.

In some places the limestones are white to gray and sufficiently pure to be of commercial importance, but in most places they are high in siliceous, ferruginous, or argillaceous impurities. Ordinarily, they are interbedded with shales and sandstones, but in some places they are interbedded with red radiolarian cherts and even with basalts. Most of those interbedded with the cherts are red and very ferruginous and contain, in addition to foraminifera, radiolaria identical with those in the cherts. Trains of nodules and irregular areas of dark flint are common in the white and gray limestones. In places the organic content is so high the limestones are black and fetid.

With the exception of the thick Calera limestone member, just south of San Francisco Bay, limestones are more abundant in the northern than in the central Coast Ranges. Lawson states that the Calera limestone occurs about 500 feet above the exposed base of the Franciscan. However, the great bulk of the limestones observed by the writer occurs in the upper part of the Franciscan, associated with the cherts, volcanics, and detrital sediments.

A red algal limestone interbedded with red radiolarian cherts and shales occurs in the western part of the Adelaida Quadrangle, in San Luis Obispo County. No algal limestone has been reported previously from the Franciscan. Small lenses of dark siliceous and argillaceous limestones are abundant in the shales and are identical with types in the Knoxville shales.

On the whole, limestones make up an exceedingly small part of the total thickness of the Franciscan and there are many sections in which they are entirely lacking.

CONTEMPORANEOUS VOLCANICS

Volcanic rocks are very widespread and commonly attain a great thickness. It is possible that minor volcanism occurred almost throughout the deposition of the Franciscan, but it is certain that volcanism did not become intense and widespread until after the deposition of many thousands of feet of shallow marine sandstones, and a corresponding sinking of the trough. There is definite evidence that the great bulk of the volcanics were submarine since they are associated with radiolarian cherts and foraminferal limestones.

Since volcanic rocks occur in the Franciscan throughout its extent in the Coast Ranges of California and southwestern Oregon, it is only natural that many types should be represented. However, the prevailing rocks are basaltic although there is great variation in the proportion of the minerals, the character of the feldspar, the texture and the degree of alteration. The volcanics occur as submarine flows, volcanic breccias and agglomerates, and as fine to coarse tuffs; tuffs are less abundant than the other types.

Some volcanics are little altered and the original nature is readily determined; many have been so altered that the nature of the original rock can be determined

only with difficulty and the examination of a large number of thin sections. Some of the alteration is due to folding, shearing, later intrusions, extensive veining, and weathering but much of the alteration took place at the time of, or immediately after, intrusion and was caused by the magmatic waters accompanying volcanism. Albitization, epidotization, uralitization, and possibly silicification were of the latter type of alteration.

The field appearance of the flows and breccias, and of the feeder dikes and necks is similar throughout the extent of the Franciscan. Ordinarily they are green to black on fresh surfaces, but they oxidize readily to various shades of brown, red brown, red, and orange red. They are nearly everywhere greatly jointed and in many places veined and it is ordinarily difficult to obtain a satisfactory hand specimen. The extensive jointing is caused by the various Cretaceous and Tertiary diastrophisms that have affected them. Because of their distinctive appearance and the colors produced by weathering, the volcanics and shallow intrusives are readily recognized even at a distance. Although readily oxidized the shallow intrusives commonly stand out in relief and occupy small knobs on the ridges.

The flows range from dense, originally glassy, basalts and variolites to porphyritic basalts with microcrystalline groundmass. They are commonly highly vesicular; the vesicles are either empty or filled with chlorite, chalcedony, quartz, albite, calcite, epidote, natrolite, and other zeolites. When unaltered the porphyritic flows and shallow intrusions contain plagioclase, which ranges from andesine to bytownite, augite, and violet to purple titanaugite, set in a pilotaxitic or intersertal groundmass. Much olivine seems to have been present but it is without exception represented by either iddingsite or antigorite even in the freshest rocks. Magnetite and ilmenite, commonly altered to leucoxene, also occur and sphene, possibly developed from the leucoxene, is present here and there.

In the dense basalts the original dark brown glass has largely altered to palagonite which ordinarily has partly crystallized to a dense aggregate in which chlorite may be recognized. In these dense rocks and in the variolites, which are rather common, skeletal phenocrysts of plagioclase, commonly albitized, and sheaf-like and plumose augite occur. Phenocrysts of this type are especially common in the pillow basalts.

Even the freshest Franciscan igneous rocks are somewhat altered; most of them are strongly altered. A comparatively simple change, and one which does not, as a rule, obscure the original nature of the rock, is saussuritization of the calcic plagioclase and uralitization of the augite. Titanaugite alters to uralite, epidote, chlorite, cloudy inclusion-rich sphene, and leucoxene; this type of alteration is more common in the intrusives than in the extrusives. Albitization of the volcanics commonly has taken place, resulting in the partial or complete conversion of the original calcic plagioclase into albite or albite-oligoclase. This may or may not be accompanied by alteration of the augite to hornblende; olivine, if present, is without exception converted into antigorite or iddingsite. The pheno-

crysts are generally more completely albitized than the microlites. Where this change goes no farther than albitization, uralitization, and serpentinization, little difficulty is experienced in determining the original nature of the rock but all too commonly this is only the beginning of alteration. Some of the changes are so great that the volcanics are converted into a granular aggregate in which a few, many or almost all of the following minerals may be present: chlorite, epidote, albite, sericite, quartz, fibrous hornblende, actinolite, zoisite, cloudy sphene, calcite, chalcedony, magnetite, and zeolites. Such highly altered rocks well deserve the common field term greenstone.

Pillow structure is common in the basalts, particularly in those that have been albitized, but it is not present in all flows. In some areas most of the volcanics are spilitic pillow basalts, but in others pillow structures are only here and there present in the flows. Highly vesicular volcanics do not show pillow structure as commonly as those that are sparingly vesicular. Practically all of the pillow basalts are submarine flows but in places they appear to have wormed their way beneath a thin cover of wet clastic or chemical sediments for a short distance. This may have taken place in a few instances near the vent from which the volcanics were erupted.

The spaces between the pillows are ordinarily filled with palagonized green glass; a few are hollow or are occupied by red chert or red limestone. The red chert between the pillows is generally indistinguishable from the ordinary chert of the Franciscan, except for the presence of radiolaria, but in places it has a spherulitic texture which is beautifully accentuated by polishing. This texture is also developed in bedded cherts on the margins of intrusives.

Although most of the volcanics appear originally to have been basaltic, other types occur. Along the east side of the Diablo Range, from Corral Hollow southward to Ortigalita Peak, a distance of about 100 miles, the exposed top of the Franciscan, west of the fault zone in this region, is commonly made up of volcanics, with thin interbeds of sediments. Many of the flows are basaltic and pillow structure is here and there developed, but dacites are not uncommon. Although about 50 thin sections of these rocks have been examined, they are so universally altered that their original nature is commonly obscure. Primary quartz is present, but the feldspars are rarely preserved. The writer has called these the El Puerto volcanics from their exposures on the creek of that name in Stanislaus County. They are intruded by small plugs and thin sills of andesite and dacite.

Volcanic breccias, agglomerates, and vent agglomerates[57] are abundant in the Franciscan and in some places cover rather large areas and attain considerable

[57] These terms are not used exactly as defined in the excellent classification of C. K. Wentworth and Howel Williams in "The Classification and Terminology of the Pyroclastic Rocks," *Nat. Research Council Bull. 89* (1932), pp. 19–53. The fragmental rocks of the Franciscan are largely submarine while the foregoing classification applies chiefly to subaerial pyroclastics.

The writer defines volcanic breccia as an accumulation of chiefly angular fragments in a matrix of finer volcanic material, with or without an admixture of contemporary sediments. Agglomerate is defined in the same way except that the fragments are rounded, largely by current action. Vent-agglomerates are angular to somewhat rounded fragments confined to volcanic vents and due chiefly to autobrecciation upon coming into contact with wet sediments. Rounding in this case is due to movement in the neck and not to water action.

thicknesses. These appear to be chiefly submarine since they are in most places clearly interbedded with contemporaneous sediments. It is possible that some are subaerial in the sense that volcanic islands may have been built up within the basin of deposition about centers of violent volcanic activity. Volcanic islands were formed during Miocene volcanism; the general character of the Franciscan outcrops, however, is rarely good enough to afford any evidence on this point.

The thickness of the fragments in the volcanic breccias and agglomerates ranges up to 2 feet; ordinarily, they vary from 1 to 4 inches. All those observed thus far are of dense or vesicular basalt. Some of the vent agglomerates contain fragments of fine-grained diabase.

The best examples of vent agglomerates occur along the crest of the Santa Lucia Range in the Cape Sun Martin Quadrangle. These occur as irregular areas of fragmental basalts, as large as ½ mile in diameter, cutting across the bedding of the Franciscan. There is little doubt that they represent autobrecciated necks; they may have been the vents through which the flows of the region reached the surface.

Crudely bedded volcanic breccias and agglomerates occur in many places. The thickest and most extensive occur in the southern end of the Santa Cruz Mountains, in southern Santa Clara County, and in several places in the northern Coast Ranges, particularly north of Clear Lake, near Copper Butte 7 miles east of Lake Pillsbury, and in the vicinity of Mount St. John, in southwestern Glenn County.

CHERTS

Davis[58] has given a complete and comprehensive account of the radiolarian cherts and little need be said here regarding petrographic details.

Cherts occur here and there in the lower part of the Franciscan, interbedded with sandstones and associated with the few volcanics, but it may be stated definitely that the maximum development of the cherts coincided with maximum volcanism. In many places the cherts are directly associated with pillow basalts although they may occur with any type of volcanics; they are more commonly associated with flows and tuffs than with volcanic breccias and agglomerates. Many lenses of chert occur that are not directly associated with volcanics at the surface, but everywhere they are in regions in which volcanics are plentiful. The association of red and green radiolarian cherts with volcanics, and particularly with spilitic pillow basalts, is not confined to the Franciscan, but is world-wide. So common is this association that it would seem that there must be some genetic connection between volcanism and siliceous sediments, particularly radiolarian cherts. Davis concluded that the silica of the cherts was introduced to the sea floor by siliceous springs accompanying volcanism. The writer[59] has pointed out that, in addition to the silica from submarine springs, a considerable amount

[58] E. F. Davis, "The Radiolarian Cherts of the Franciscan Group," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11 (1918), pp. 235–432.

[59] N. L. Taliaferro, "The Relation of Volcanism to Diatomaceous and Associated Siliceous Sediments," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 23 (1933), pp. 48–49.

might have resulted from the interaction of hot lava and sea water. Whatever the mode of introduction of the silica, the volcanics appear to have been its ultimate source. In 1933, the writer described siliceous springs and sinters associated with the Miocene cherts of California. Since that time other widely scattered submarine siliceous sinters have been observed. Such sinters have not been found in association with the Franciscan cherts, but anyone familiar with Franciscan outcrops in general realizes that they might be difficult to discover. Furthermore, the ordinary porous structures of sinters would be readily destroyed by the pressures caused by the depth of burial and the weight of later Cretaceous and Tertiary sediments. Notwithstanding the lack of direct evidence, it is believed that at least a part, if not most, of the silica of the cherts was derived from submarine springs connected with volcanism. The iron and manganese commonly associated with the cherts is believed to have the same origin. These deposits are described later.

Certain of the cherts associated with Ordovician graptolitic shales appear to have originated in basin-like depressions in the sea floor[60] at considerable depths and it is possible that the Franciscan cherts were deposited in basins where there were few, if any, currents (but not at any great depth, as is shown later). However, there is little evidence for and much against this hypothesis. The cherts are commonly associated with coarse sandstones and even conglomerates which do not indicate a lack of currents. It is possible that they accumulated in small irregularities of the sea floor that permitted the local concentration of siliceous oozes and afforded some portection from the influx of detrital sediments. The only evidence for this is the fact that, even though the cherts are contained in sandstones as small or great lenses, the individual chert layers are rhythmically bedded with shales as a rule.

The only thick and numerous lenses of chert not directly associated with abundant flows occur on the east side of the northern end of the Diablo Range in Alameda and Stanislaus counties. Even here volcanics are very abundant in the northern part, becoming scarce southward. In this region the red and green radiolarian cherts are interbedded with red and green shales and the chert-shale lenses are enclosed in fine to coarse sandstones, grits, gravels, and conglomerates. These beds occupy the crest and flanks of the great Mount Oso anticline; west of this anticline, where the same horizons reappear, both volcanics and cherts are present. Thus, even in this region there are abundant contemporaneous volcanics both north and west. It is possible that, in this particular area, the silica was derived from more distant contemporaneous volcanics and was carried in, mixed with fine detrital material and accumulated in local basin-like depressions of the sea floor. The coarser detrital sediments might well represent periods of flood.

In most places the cherts are interbedded with red, green, or black shales but in a few places the interbeds between the chert lenses are fine- to medium- or

[60] Rudolph Rudemann and T. Y. Wilson, "Eastern New York Ordovician Cherts," *Bull. Geol. Soc. America*, Vol. 47 (1936), pp. 1535–86.

even coarse-grained arkosic sandstones of the ordinary type. The same rhythmic bedding occurs even when the interbeds are of sandstone. Where the cherts are interbedded with sandstones the sandstones commonly contain small angular chips of the chert, as though chert lenses had occasionally been scoured or broken by the influx of sand. This is additional proof of the shallow-water origin and rapid hardening of the chert.

The early idea of most continental writers regarding the abyssal origin of the cherts has been discussed by Davis and the writer, who have shown the cherts to have been shallow-water deposits. Nevertheless this ancient idea seems to persist[61] although it has been abandoned by later continental geologists.[62] At the risk of repeating an old story the writer reviews the evidence for the shallow-water origin of the cherts.

Lenses of chert of great linear extent and hundreds of feet in thickness are not common in the Franciscan. The chert ordinarily occurs in scattered lenses rarely as much as a mile in length. These are enclosed in sediments of whatever type prevail in the region, shales, tuffs, sandstones, conglomerates, or volcanics. Fine to coarse sandstones occur almost everywhere in the vicinity of, or actually enclose, the cherts, and conglomerates are present in many places. As an illustration, a section west of Burnett Creek in the San Simeon Quadrangle, a typical section, may be described. Here the beds dip southeastward at an average angle of 30° and are reasonably well exposed. Most of the sediments are medium to coarse arkosic sandstones, but there are many interdigitations of shales, conglomerates, pillow basalts, and cherts. All but the sandstones are in comparatively thin beds, 1–20 feet. Glaucophane schists developed from the sandstones are here and there present as *bedded* layers having the same attitude as the enclosing sediments. These are described later. There are dozens of repetitions of sandstones, conglomerates, volcanics, and cherts. Conglomerates with cobbles up to 6 inches in diameter are present both above and below cherts and close to them. Furthermore, the cherts are lenses, many less than 100 yards in length. It is highly unreasonable to suppose that the sea bottom was repeatedly depressed and uplifted thousands of feet from the neritic to the abyssal zone, to permit the accumulation of 5 feet of chert preceded and followed by coarse shallow-water deposits. It is only necessary to observe the field relations of the cherts to become convinced of their shallow-water origin.

The rhythmic bedding of cherts and shales has been discussed by Davis and the writer, and need not be discussed here. There is abundant proof that the colloidal silicic acid in an ooze has the ability to free itself from impurities when flocculated.

In summary, it may be stated that the maximum development of the cherts coincided with maximum volcanism and that the volcanics appear to be the ulti-

[61] W. H. Bucher, *The Deformation of the Earth's Crust*, pp. 3–4. Princeton Univ. Press (1933).

[62] Jacques de Lapparent, "Roches à radiolaires du Dèvonian de la vallée de la Bruche," *Bull. Serv. Carte Géol. d'Alsace et de Lorraine*, Vol. 1 (1924), p. 62.

mate source of the silica, as well as the iron and manganese so commonly associated with the chert. The silica was originally flocculated as colloidal silica which rapidly hardened to opal; ordinarily the opaline silica has been converted to a very fine-grained mosaic of chalcedony and, or, quartz. Radiolaria are nearly everywhere present and may be abundant, but they contributed only a minor amount of the silica. The abundance of silica in the water afforded optimum conditions for the growth of the radiolaria. The cherts are associated with coarse clastics and were deposited in shallow water.

MANGANESE AND IRON ASSOCIATED WITH CHERTS

Most of the radiolarian cherts of the Franciscan are red because of the presence of iron oxide and to a lesser extent manganese oxide, and, occasionally, both iron and manganese become so abundant as to form commercial ores. The siliceous iron deposits have never been worked but the manganese deposits have been mined at hundreds of localities, most of which have been visited by the writer.

With two minor exceptions, all the known deposits of manganese in the California Coast Ranges occur in intimate association with the radiolarian cherts. Most of the deposits are oxidized at the surface to the black manganese oxides, psilomelane, pyrolusite, and wad (oxides mixed with clayey impurities), but this change ordinarily does not extend far beneath the surface; the primary ores are encountered at depths which vary from practically nothing to 30 or 40 feet. The primary material is of two kinds, manganese carbonate and neotocite, both of which occur as bedded lenses in thin- to thick-bedded radiolarian chert. Where unoxidized, the carbonate is light to dark gray in color, ordinarily dense and fine-grained; its texture is much like that of the limestones associated with the Franciscan. It is commonly cut by veins of pink rhodochrosite just as limestones are veined with calcite; the pink rhodochrosite bears the same relation to the dense gray manganese carbonate as calcite does to dense limestone. Under heat and pressure manganese carbonate crystallizes in the same manner as limestone.

Neotocite is a light to dark liver-brown manganiferous opal with the general formula, X manganese oxide (or hydroxide) $\cdot YSiO_2 \cdot ZH_2O$. The exact state of oxidation of the manganese is not known. If unaltered and not recrystallized, manganese oxide varies up to 40 per cent and H_2O up to 12 per cent. Like opal it is amorphous but, also like opal, readily recrystallizes under heat and pressure. With slight pressure it is converted to a manganiferous chalcedony; greater metamorphism converts it into rhodonite, or rhodonite and quartz, according to the amount of manganese originally present. Rhodonite occurs in the manganese deposits of the Franciscan, but in most places the metamorphism has not been sufficient for the manganese silicate to form; both rhodonite and spessartite are commonly present in the older more metamorphosed manganese deposits of the Sierra Nevada, which are also associated with red radiolarian cherts.

The manganese oxide may be readily leached from the original opaline neotocite by hydrochloric acid, leaving a friable but coherent skeleton of opal.

In some deposits manganese carbonate greatly predominates and in others neotocite, but both are commonly present. It is not uncommon to find trains of spherules of manganese carbonate (commonly changed by pressure to rhombs) in neotocite; these may become increasingly abundant and pass into a relatively pure bed of carbonate. Lenses of neotocite are abundant in many carbonate ores.

In nearly every place where the relations between the primary ore and the chert are observable, and where there has been no faulting or shearing, the ore is seen to occur as bedded lenses, parallel with the bedding of the enclosing cherts. The primary neotocite and manganese carbonate, like the chert, occur as lenses. Generally, a series of such lenses occurs at the same stratigraphic horizon. There may be several ore lenses in the same body of chert, separated by a few feet of chert.

Ordinarily there is a sharp contrast between the ore lenses and the enclosing chert, especially on the upper and lower sides. However, it is not uncommon to find the ore, especially the neotocite, grading laterally into ordinary radiolarian chert through a gradual decrease in the manganese content; in some places this change takes place across the bedding and there are thin beds of siliceous ore, or manganiferous chert, on the walls of the ore lenses. Where unoxidized, these have the same general appearance as the chert.

In the vicinity of the ore bodies and commonly for some distance away from them the cherts are stained on the surface with black manganese oxide. Below the oxidized zone, such cherts are found to contain scattered spherules, or rhombs, of manganese carbonate or minute lenses of a neotocite high in silica.

Essentially the neotocite is a highly manganiferous chert. There is a possibility that the manganese may be present as a colloidal hydroxide as the neotocite is ordinarily higher in water than the associated chert. Apparently this hydroxide, or oxide as the case may be, was included in the mesh structure[63] of the original silica gel at the time of its formation. The manganese must have been in a colloidal state comparable with the silica, otherwise diffusion would have taken place, resulting in alternate bands of manganese and opal.

There is no evidence of replacement of the chert by manganese. The presence of unreplaced radiolaria in neotocite, in one instance, is evidence against replacement. The nature of the neotocite indicates that the manganese and silica were introduced contemporaneously. The presence of manganese-stained chert pebbles, associated with pebbles of ordinary radiolarian chert, in Franciscan conglomerates is regarded as corroborative evidence.

All of the available evidence clearly indicates that the neotocite and manganese carbonate lenses are syngenetic with the enclosing chert. It is believed that the volcanics were the ultimate source of the manganese.

Only two exceptions to this mode of occurrence have been reported. According to Parker D. Trask,[64] manganese oxide locally occurs as a replacement of Franciscan limestone on the margin of an intrusive greenstone. This occurrence is

[63] N. L. Taliaferro, "Some Properties of Opal," *Amer. Jour. Sci.*, Vol. 30 (1935), pp. 450–74.

[64] Personal communication.

near the coast, north of Shelter Cove in Mendocino County. The other case is a variation of the ordinary mode of occurrence rather than an exception. In the Vann mine, in Lake County, a thin bed of arkose sandstone underlies the manganese deposit; both ore and sandstone are enclosed in thin-bedded radiolarian cherts.

The primary ores are readily oxidized at the surface and along joints which extend below the surface. Space does not permit a discussion of this complex process. During oxidation a variable amount of migration of the oxides has taken place and they may penetrate the enclosing rocks as veinlets along joints, obscuring the true relation between ore and enclosing rock. However, even the thoroughly oxidized ore lies parallel with the bedding. In many places the oxidization of the original neotocite has left a manganese-stained, honey-combed skeleton of silica as a core surrounded by high-grade oxide ore. Beneath the oxidized ore the primary ore is ordinarily very siliceous; this is especially true when neotocite predominates.

Iron oxide is nearly everywhere present in the cherts and in places it, like the manganese, is concentrated into lenses; manganese is nearly everywhere present. The iron deposits have no commercial value because of their high silica content and have not been studied to the same extent as the manganese ores. However, the little that has been done indicates that they are of the same general nature. Both ferruginous cherts and siliceous iron carbonates occur although the former are more abundant.

There is nothing new or startling in the idea of the discharge of iron and manganese compounds from volcanic springs, either subaerial or submarine. The emission of considerable quantities of iron from submarine volcanic springs near Santorin (Thira), in the Mediterranean southeast of Greece, has been described in considerable detail by Behrend.[65] The red discoloration of the sea in the vicinity of Santorin has been observed at various times since 1650. The discharge of iron carbonate is said to have been practically continuous from 1707 to 1848 and from 1869 to 1933. The sea in the vicinity was colored yellow, green, and red over a considerable area, especially during the volcanic eruptions when the submarine springs seem to have been most active. However, the springs discharge iron carbonate and gases even during periods of quiesence. The water from the springs is said to be a "dirty dark green color," which changes quickly to brownish yellow and red due to the appearance of iron hydroxide; the original green color is due to ferrous carbonate. The temperature of the green water is said to range from 32° to 43°C. Iron chloride is also reported as being present. The iron hydroxide formed at the surface sinks and covers the sea bottom in the region. Had silica been discharged, deposits very similar to those in the Franciscan might readily have formed.

[65] Fritz Behrend, "Eisen und Schwefel Fordernde Gasquellen auf den Kameni Inseln," in Hans Reck, *Santorin. Der Werdegang eines Insel vulkans und sein Ausbruch, 1925–1928,* Vol. 2, pp. 323–28. Berlin (1936).

The iron and manganese commonly associated with the Franciscan cherts is believed to have originated in the same manner as the silica, from submarine volcanic springs or the reaction of hot lava with sea water.

BASIC AND ULTRABASIC INTRUSIVES

There are numerous intrusions in the Franciscan almost throughout its extent. These take the form of plugs, dikes, sills, and laccoliths; many of the concordant intrusions are of great thickness and extent. Irregular sill-like bodies are the commonest and largest type of intrusion. These were emplaced before the sediments had been uplifted from the basin of deposition; they are folded with the sediments they intrude. Although essentially concordant, the sill-like bodies, both large and small, commonly transgress the bedding and thin and thicken in short distances. It is not uncommon to find a single thick sill on one side of a syncline represented by a number of thin sills separated by included leaves of sediments on the other side. Leaves of the intruded rocks, either sediments or volcanics, commonly occur. In some places these have been completely converted into the characteristic schists but commonly they show no signs of alteration aside from a baking of the shales and a bleaching of the cherts. The greatest number of these intrusions are ultrabasic and basic, but there are a few small plugs and sills of andesite and dacite porphyry connected with the El Puerto volcanics along the east side of the northern part of the Diablo Range.

These intrusive bodies are widely distributed both geographically and stratigraphically, being found throughout the extent and thickness of the Franciscan and Knoxville. However, the thickest and most extensive ultrabasic sills occur in the upper part of the Franciscan and the lower part of the Knoxville; in places they rise almost to the top of the Knoxville.

It is, of course, not known if these igneous rocks were intruded at the same time or whether they came in throughout the deposition of the Franciscan and Knoxville. They cut practically all parts of the Franciscan and Knoxville, including the volcanics but some of the serpentines are intruded by plugs of basalt. It is believed that the main period of intrusion did not begin until after the beginning of maximum volcanism and continued almost until the close of the Jurassic; the evidence for this is given under the discussion of the Knoxville. However, even the youngest of these basic and ultrabasic rocks were emplaced prior to the beginning of the deposition of the Paskenta stage of the Lower Cretaceous since débris of these rocks is abundant in the basal Paskenta conglomerates. In fact great mud flows of serpentine, even larger than the Miocene Big Blue of the Coalinga region, occur in the lower part of the Paskenta in Colusa County. The intrusion of the rocks of this particular suite is, therefore, confined to the late Upper Jurassic.

Several different petrographic types are represented, but the commonest is serpentinized peridotite. The peridotites are accompanied by gabbros and diabases; anorthosites occur in very small areas. Commonly the peridotites

have been so completely serpentinized that it is difficult to determine the exact nature of the original rock, but in many places serpentinization has been incomplete and the original nature is apparent. Most of the serpentines appear originally to have been harzburgites (saxonites), made up of 60–90 per cent of olivine and the remainder largely of enstatite; picotite, chromite, and magnetite are almost everywhere present as minor accessories. In some places the original rock appears to have been dunite, but in most places it has been almost completely serpentinized. In places the original rock appears to have been the variety known as wehrlite, in which the pyroxene was diallage; these occurrences, however, are rare. Palache[66] described a lherzolite-serpentine containing diallage in addition to enstatite, and a hypersthene diabase, from San Francisco. The writer has examined thin sections of these rocks; the diallage is not abundant and is subordinate to the enstatite. Hypersthene is not abundant in the diabase and is greatly subordinate to augite and its alteration product, green hornblende; the hypersthene is the pale, faintly pleochroic, iron-poor variety. Lherzolites and wehrlites occur but they do not appear to be as abundant as harzburgites (saxonites).

Nearly without exception the olivine greatly exceeded the pyroxene, but occasionally there are small masses within larger bodies of serpentine that are chiefly or wholly made up of rhombic pyroxene, largely serpentinized. These serpentinized pyroxenites are much coarser-grained than the peridotites they accompany; crystals up to 6 inches in length are not uncommon. They also vary greatly in grain size from one crystal to the next and in this respect resemble pegmatites. They are differentiates of the peridotites, as are the gabbros and anorthosites.

The serpentinization of the ultrabasic rocks took place in a late magmatic stage and was accomplished by volatiles and waters accompanying the intrusion probably aided by the connate water in the sediments through and into which they were intruded. In most of the intrusions serpentinization has been rather thorough, but here and there remnants of the original rock remain. The size of the intrusion has little relation to the degree of serpentinization as the great sill in the heart of the Coalinga anticline, one of the thickest serpentine sills in the state, is completely serpentinized.

Although there are a few possible exceptions, the thickest and most completely serpentinized sills occur in the upper part of the Franciscan and the lower part of the Knoxville. In fact it is believed that some of the stratigraphically higher sills were largely serpentinized before complete emplacement; the change took place as they rose through a great thickness of sediments high above their source. Such sills rarely show any pneumatolytic contact effects on their borders as the magmatic vapors and solutions had been largely utilized in serpentinization. A considerable increase in volume was produced by the hydration of the original peridotite into serpentine and the serpentine bodies are greatly sheared internally.

[66] Charles Palache, "The Lherzolite-Serpentine and Associated Rocks of the Potrero, San Francisco," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1 (1894), pp. 161–79.

Furthermore, this increase in volume resulted in most places in a definite shearing of the margins; the original contacts are rarely observable because of this increase in volume and shearing. The contacts are commonly sheared and slickensided, giving an erroneous impression of strong faulting; in studying the large serpentine bodies this fact always must be kept in mind.

The fact that the thickest sills occur high in the Franciscan might be taken as indicating that the main period of intrusion began during or after maximum volcanism and after the accumulation of a thick prism of sediments. The sills would find greater difficulty in forcing their way into the lower part of the Franciscan because of the great weight of the overlying sediments; higher in the section they could spread much more readily.

The large serpentine mass in the upper part of the Franciscan in the vicinity of New Idria is interpreted as an anticlinally folded sill for several reasons. Where the relations are observable it parallels the bedding of the Franciscan in general and there are numerous leaves of Franciscan within the body which have the same general attitudes as the margins. Furthermore, near the center of the mass, on Clear Creek, there are several leaves of sediments and volcanics which are anticlinally folded and plunge westward away from the crest of the dome which is at the east in the midst of the serpentine mass. Serpentine, in the same position, is encountered in the crest of two anticlinal folds on the west, toward which direction it thins greatly. The crest of the Coalinga anticline, in which it is thickest, may be a laccolithic swelling on this great sill. These relations are shown on the cross sections accompanying the writer's 1941 paper on the central Coast Ranges.

From measurements of attitudes on the margins and on the included leaves of Franciscan this sill must be at least 5,000 feet thick. West of Paskenta, in Tehama County, there is a somewhat similar, but even greater, increase in thickness of a great serpentine sill. In this region the serpentine is more than a mile in thickness and it transgresses several thousand feet of the Knoxville sediments. On the east the lowermost Lower Cretaceous transgresses at least 7,000 feet of Knoxville sediments directly opposite to and above the thickened area of the sill. It is hardly conceivable that the intrusion of bodies of such thickness into unconsolidated sediments could have taken place without uplift of the surface. The evidence in the Paskenta district and at New Idria indicates that the intrusion of these thick sills actually caused local uplifts. The absence of Lower Cretaceous and the great thinning of the Upper Cretaceous about the New Idria sill has been interpreted as being due to Cretaceous folding. In the opinion of the writer the local increase in thickness of the sill, possibly aided by folding, was the cause. He does not believe that there is any escape from the conclusion that the intrusion of exceptionally thick sills caused local uplift of the sea floor.

The largest plug of ultrabasic rock in the California Coast Ranges, south of the Klamath Mountains, is that of Burro Mountain, in the Cape San Martin Quadrangle, southern Monterey County. This plug, which is slightly elongate

northwest and southeast, has a width of 1.5 miles and a length of 2 miles; irregular sill-like apophyses extend from its southern end. Only the margins of the plug are serpentinized, the interior being fresh peridotite. The unaltered core has a diameter of 1–1.25 miles.

Burro Mountain, which is entirely occupied by the plug, has an elevation of 2,822 feet and lies about midway between the crest of the Santa Lucia Range and the Nacimiento River. It is 500 feet lower than the crest of the range on the west and 1,800 feet higher than the Nacimiento River; it rises 500–800 feet above the immediately surrounding country. Los Burros Creek is a superimposed stream that cuts a meandering course through the center of the plug, forming a narrow precipitous gorge 1,500 feet deep in which unaltered peridotite is exposed from top to bottom. The mountain forms a conspicuous feature of the landscape because of the brown to orange color of the weathered peridotite.

The peridotite has been studied by G. L. Bell[67] from whom the following petrographic details are taken. The most abundant mineral is olivine which forms 70–80 per cent of the rock, the remainder being chiefly enstatite, with minor amounts of picotite, chromite, and magnetite. The olivine, as determined from its optical properties and indices, varies from forsterite$_{82}$ foyalite$_{18}$ to Fo_{72} Fa_{28}. The optical properties and indices of the enstatite indicate an average composition of $MgSiO_{3(87)}$ $FeSiO_{3(13)}$. Serpentine may be present up to 6 per cent, but is absent in many thin sections.

The average mineral composition, excluding any serpentine that may have developed, based on specimens from the upper part of the plug is as follows.

	Per Cent
Olivine	75.0
Enstatite	22.0
Picotite	2.0
Chromite	0.5
Magnetite	0.5
	100.0

The rock is thus a typical olivine-rich harzburgite (saxonite).

From the foregoing mode the writer has computed the chemical composition to be as follows.

	Per Cent
SiO_2	42.61
Al_2O_3	.55
Fe_2O_3	.15
FeO	14.64
MgO	40.90
Cr_2O_3	1.15
	100.00

This is in agreement with the composition of many peridotites. Unfortunately there are no analyses of unaltered California peridotites with which this may be compared.

[67] G. L. Bell, "A Geologic Section of the Santa Lucia Mountains, California," unpublished master's thesis, Univ. Calif. Library.

Gabbros and diabases are commonly associated with the serpentinized ultrabasics and are regarded as differentiation products; small dikes and irregular areas of anorthosite also occur. Ordinarily the proportion of gabbro and, or, diabase in any one serpentine sill is small, but in places they predominate and form thick independent sills or small plugs, dikes, or laccoliths. The boundaries between peridotite, gabbro, and diabase are both sharp and gradational. Where sharp the basic rocks appear to have intruded the ultrabasics.

Some of the basic rocks are fresh even where associated with thoroughly serpentinized peridotites, but many are saussuritized and uralitized. There is considerable variation in mineral composition and proportions and in grain size. The feldspars are ordinarily labradorite and bytownite; they are rarely if ever zoned, but some have rims of oligoclase. In some localities they have been little altered, but in others they are partly or completely destroyed. Augite, either fresh or partly or completely altered to green hornblende, is the commonest ferromagnesian mineral; titan-augite, hypersthene, and diallage also occur. Olivine appears to have been abundant in some gabbros, but it is almost everywhere converted into antigorite. Some serpentinized troctolites occur but augite ordinarily predominates over serpentinized olivine. Magnetite and ilmenite are common accessories and picotite and sphene are not rare. Quartz is rare but in places makes up 5 or 6 per cent. Granodiorites have been reported in the Tesla region, but they are simply gabbroic differentiates containing a little quartz. The feldspar in these quartz-gabbros ranges from basic labradorite to bytownite; the augite is commonly uralitized.

Banded gabbros in which there is a crude separation of the plagioclase and pyroxene into irregular layers and lenticals are not uncommon. Excellent examples of such banded gabbros associated with serpentine are found in the Piedras Blancas Quadrangle north of Arroyo de la Cruz. The banding appears to be primary and is parallel with the contacts. The literature relating to primary banding in general has been reviewed by Coats[68] and a comparatively simple mechanism suggested. It is possible that the banding in the gabbros and the various rock types, gabbro, diabase, anorthosite, and quartz-gabbro, associated with the serpentines, are the result of gravitational differentiation as in places the basic rocks occur near the top of the sills. However, this is not a constant relationship and most of the sills do not offer any evidence of gravitational differentiation. The only indications of gravitational differentiation noted by the writer occur in the northern part of the Diablo Range and in the region north of Middletown in Lake County.

Great variation in alteration is shown by the gabbros and diabases; in some the original constituents, except olivine if present, are unaltered, but in others both the feldspars and the pyroxene are partly or completely altered. Some of the feldspars are little altered, but the augite is almost completely changed to

[68] R. R. Coats, "Primary Banding in Basic Plutonic Rocks," *Jour. Geol.*, Vol. 44 (1936), pp. 407–19.

green hornblende; in others the augite is still unattacked, but the feldspars almost completely saussuritized.

Plugs, dikes, and irregular sills of basalt and fine-grained diabase are very numerous in some regions. Some of these may have been the feeders of flows, but most of them appear to be independent intrusions. Ordinarily these are small, but some of the plugs and sills approach the size of the peridotite bodies. The presence of great numbers of such intrusive bodies in a region has had a marked effect on the appearance of the Franciscan as the sediments and flows have been crushed against these more rigid masses during the various periods of folding since the Lower Cretaceous. In such regions the sediments are greatly disturbed, sheared, and crushed and great landslides are especially numerous.

Both the basic and ultrabasic intrusives and the rocks with which they are in contact are commonly veined with calcite, albite, and quartz. In places the calcite veins contain small amounts of chalcopyrite and its alteration products. The magmatic waters accompanying the intrusions were the source of the carbonates, silica, and copper since boulders of copper-stained veins are found in the basal Lower Cretaceous conglomerates.

Chromite and picotite are nearly everywhere present in the ultrabasic rocks as disseminated grains, and not uncommonly there are economically important concentrations. These occur as irregular lens-like pods or segregations and as banded deposits in which bands of almost barren serpentine alternate with bands containing 5–25 per cent chromite. In some places the chromite occurs as pellet-like aggregates of grains ranging from coffee-bean to walnut size scattered through the serpentine; these are given the appropriate name of "leopard ore" from their spotted appearance.

Commonly these deposits are of high grade and approach the standard composition of chromite, but some of the chromite of even the massive black pods actually is a chrome-rich picotite containing as little as 33 per cent Cr_2O_3. Where the banded deposits contain chrome-rich picotite rather than true chromite great difficulty is encountered in their concentration.

Probably the prevailing opinion at the present time is that the chromite was introduced in a late magmatic stage, during or even after serpentinization, and that its concentration was controlled and guided by strong shear planes in the serpentinized peridotite. The writer does not wish to discuss this matter in detail here, but simply wishes to point out that there are many objections to this hypothesis. The disseminated chromite and picotite in both the fresh and serpentinized peridotites crystallized at the same time as the primary olivine and pyroxene. Since the great bulk of the peridotites have been serpentinized, it is only natural that most of the deposits should be found in serpentine; however, high-grade concentrations of chromite also occur in fresh unserpentinized peridotite. It is true that many deposits lie along shear planes, but in most of the occurrences observed by the writer these are obviously later than the deposits, which have been sheared and smeared along the planes of movement.

GLAUCOPHANE SCHISTS AND RELATED ROCKS

Introduction and historical review.—The schists, with their striking colors and varied and extraordinary mineral assemblages, are among the most interesting petrographic types found in the Franciscan. A number of strongly contrasted views regarding their origin have been expressed; the frequent misinterpretation of their origin and the type of metamorphism they represent has contributed to the general confusion of the Franciscan problem. The apparent thoroughness of recrystallization and the number of new minerals developed give the impression of intense metamorphism and have been among the most important factors causing an all too common belief in the advanced stage of alteration of the Franciscan in general.

As has been shown in the historical review, Becker and Whitney regarded the schists, serpentines, diabases, and cherts, as metamorphosed Lower Cretaceous and implied a widespread regional metamorphism although they recognized that these rocks passed rapidly into unaltered sediments. Ransome[69] gave the first detailed account of the mode of occurrence and petrography of these rocks and concluded they were developed by contact action on the borders of basic and ultrabasic intrusives. Lawson,[70] in various publications issued between 1895 and 1914, expressed similar views based on field observations. In 1898 Van Hise, from observations in Calaveras Valley, along the Calaveras fault, concluded that they were developed from igneous rocks by dynamic metamorphism. Nutter and Barber[71] recognized that some of the schists had been developed at the contacts of basic igneous rocks but did not believe that this was the origin of the "normal" schists. They reached the strange conclusion that they were isolated outcrops of an older, regionally metamorphosed series that underlies the Franciscan throughout the Coast Ranges.

Holway[72] compared them with the Scandinavian eclogites and stated that they were derived from intrusive gabbros. The green pyroxene (diopside) was called omphacite and the actinolite smaragdite. The eclogites of Norway and the Alps are the result of plutonic metamorphism and are everywhere associated with granulites, gneisses, and other completely metamorphosed rocks. The great difference in the mode of occurrence and association of the true eclogite and the Franciscan schists was not commented on by Holway. Smith,[73] who gave an excellent description of these rocks based on widespread observations throughout

[69] F. L. Ransome, "The Geology of Angel Island," *Univ. California Pub.*, Vol. 1 (1894), pp. 193–240.

[70] A. C. Lawson, "Sketch of the Geology of the San Francisco Peninsula," *U. S. Geol. Survey 15th Ann. Rept.* (1895), pp. 399–476; "San Francisco, California," *U. S. Geol. Survey Geol. Atlas Folio 193* (1914).

[71] E. H. Nutter and W. B. Barber, "On Some Glaucophane and Associated Schists in the Coast Ranges of California," *Jour. Geol.*, Vol. 10 (1902), pp. 738–44.

[72] R. S. Holway, "Eclogites in California," *Jour. Geol.*, Vol. 12 (1904), pp. 344–58.

[73] J. P. Smith, "The Paragenesis of the Minerals in the Glaucophane-Bearing Rocks of California," *Proc. Amer. Philos. Soc.*, Vol. 45 (1906), pp. 183–242.

the Coast Ranges, concluded that they were caused by the contact metamorphism of sandstones, shales, cherts, and basic igneous rocks, on the borders of ultrabasic and basic intrusives.

From the foregoing it is seen that, based on observations in the same general area, very diverse conclusions regarding the origin of these schists have been reached. They have been ascribed to both dynamic and contact action and compared with the results of extreme plutonic metamorphism. Although the majority of writers have concluded that these rocks are the result of contact action, the only conclusion possible to any who have studied these schists in the field, the writer has been greatly surprised at the general lack of agreement among geologists at the present time, based on published reports and personal conversations, as to the meaning and mode of origin of these schists. Harker,[74] who was only familiar with the Franciscan schists through the literature, discussed them under both contact and dynamic metamorphism. However, he makes a clear distinction between these schists and eclogites. Glaucophane schists have been developed in Great Britain and other parts of the world by the dynamo-thermal metamorphism of basic igneous rocks, but their mode of occurrence is very different from that of the Franciscan schists.

Because of the large number of minerals in these rocks, or in the veins associated with them, many of which are comparatively exceptional and some of which are rare, there is an extensive literature dealing with their petrography, mineralogy, and chemistry. Important papers on their mineralogy have been contributed by Smith,[75] Palache,[76] Ransome,[77] Murgoci,[78] Blasdale,[79] Louderback,[80] Louderback and Sharwood,[81] Diller,[82] Pabst,[83] and Mielenz.[84] The most complete account of the petrography of the schists in general is that by Smith. Mielenz gives an excellent description of the schists in a local area.

[74] A. Harker, *Metamorphism, a Study of the Transformation of Rock Masses*, pp. 134, 291, 292, 309. London (1932).

[75] J. P. Smith, *op. cit.* (1906).

[76] C. Palache, "On a Rock from the Vicinity of Berkeley Containing a New Soda Amphibole," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1, No. 6 (1894).

[77] F. L. Ransome, "On Lawsonite, a New Rock-Forming Mineral from the Tiburon Peninsula, Marin County, California," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1 (1895), pp. 301–12.

[78] G. Murgoci, "Contribution to the Classification of the Amphiboles; on Some Glaucophane Schists and Syenites," *ibid.*, Vol. 4 (1906), pp. 359–96.

[79] W. C. Blasdale, "Contribution to the Mineralogy of California," *ibid.*, Vol. 2 (1901), pp. 327–48.

[80] G. D. Louderback, "Benitoite, Its Paragenesis and Mode of Occurrence," *ibid.*, Vol. 5 (1909), pp. 331–80.

[81] G. D. Louderback and W. J. Sharwood, "Crocidolite-Bearing Rocks of the California Coast Ranges" (abstract), *Bull. Geol. Soc. America*, Vol. 19 (1908), p. 659.

[82] J. S. Diller, *U. S. Geol. Survey 17th Ann. Rept.* (1896), p. 454 *et seq.*

[83] A. Pabst, "The Garnets in the Glaucophane Schists of California," *Amer. Mineralogist*, Vol. 16 (1936), pp. 327–33.

[84] R. C. Mielenz, "The Geology of the Southwestern Part of San Benito County, California," unpublished doctor's dissertation, University of California Library (1937).

Although many analyses of the minerals in the schists have been made, there are comparatively few analyses of the Franciscan schists and papers dealing with their chemistry are not numerous. The chemistry of glaucophane schists from various parts of the world has been discussed by Washington[85] who, from analyses available at the time, divided them into two groups, on the basis of silica percentage. A sufficient number of analyses are not available to justify such a division.

Field occurrence.—Before discussing the petrographic and mineralogic character the field occurrence of these rocks is described since the chief evidence for their origin is their mode of occurrence and field relationships; brief statements regarding their field relations in local areas have been published, but no comprehensive account has been given. The present description is based on observations throughout the Coast Ranges of California and Oregon.

In most places the schists are directly and intimately associated with basic and ultrabasic rocks, but small areas occur that have no visible surface connection with intrusives. In the first place, the schists occur in relatively small areas in the midst of unaltered sediments or as inclusions within ultrabasic rocks. Where there are a number of small areas of schist in regions of rather deep weathering and only moderate relief they give a false impression of size since they are more resistant than the unaltered sediments and volcanics and hence stand out as small knobs. This is the case in north Berkeley, where they are shown on the San Francisco sheet of the San Francisco folio as cropping out in an area $3\frac{1}{2}$ miles long and more than a mile wide. Actually they occupy only a fraction of this area and occur as small isolated outcrops separated by weathered, soil-covered serpentine and sediments. Only rarely are the individual schist areas more than $\frac{1}{2}$ mile in length; ordinarily they are much smaller.

One of the largest continuous areas is in the Healdsburg Quadrangle, Sonoma County. This belt of schists appears from beneath valley alluvium a mile southwest of Healdsburg and extends northwestward for approximately 7 miles; it varies from $\frac{1}{4}$ mile to a mile in width. The schists, as well as the serpentine and unaltered sediments, have been folded into an asymmetric syncline with a comparatively gentle southwest flank and a steep northeast flank. Along the southeast end of the syncline the schists occupy only the southwestern limb, the northeastern being made up of sandstones and shales, the unaltered equivalents of the schists. A thin, discontinuous sill of serpentine underlies the schists on the southwest side of the syncline and is in places present beneath the schists on the northeast side. Half a mile north of the schists there is a thick (more than 1,000 feet) and continuous sill of serpentine which parallels the schist belt. This is not only the longest continuous belt of schists known to the writer, but also the thickest. Because of minor crumpling within the syncline it is difficult to measure the thickness of the schists; they appear to be about 2,000 feet thick. As in most

[85] H. S. Washington, "A Chemical Study of the Glaucophane Schists," *Amer. Jour. Sci.*, 4th Ser., Vol. 11 (1901), pp. 35–59.

places, it is possible to differentiate between the schists developed from shales and those developed from sandstones. The sandstones and shales change within a short distance into schists having alternate coarse- and fine-grained layers. In places, there are small areas of little altered sediments within the schists; these have the same attitude as the schists.

There are a number of much smaller areas of schist on the tops of serpentine sills 3 miles northeast of Healdsburg. However, not all of the serpentine intrusions in this area caused the formation of schists from the sediments. About 5 miles south of the southern end of the large schist belt there is a serpentine-gabbro sill with an outcrop width of 1,500–2,000 feet about which almost no schist has been developed. Irregular areas of very coarse serpentinized pyroxenite are common in the serpentine and the gabbro is cut by narrow dikes of anorthosite.

The schists have no prevailing attitude over wide areas; they may be nearly flat, vertical, or contorted. Their attitude is governed by the attitude of the sediments from which they were derived or by the intrusive. The planes of schistosity are parallel with the adjacent unaltered sediments; their attitude is governed by the local structure.

Since sills are by far the commonest type of ultrabasic intrusion most of the schists are found near such bodies. Most of the schists are developed from sediments or volcanics forming the roof of the sill or from included leaves within the sill. If any schists are formed by the intrusion, the greatest development occurs on the roof, which is to be expected since the easiest avenue of escape of the volatiles and hot solutions would be upward. Small patches of schists also occur on the bottoms of sills.

There are many excellent examples of the localization of the schists on the upper surface of sills. In the northern part of the Tiburon Peninsula, which extends southeastward into San Francisco Bay, there is an irregular sill-like intrusion of harzburgite, almost completely converted into a massive bastite serpentine that lies in the trough of a faulted syncline. The sill, which has a maximum thickness of 400 feet, is roughly parallel with the bedding of the rocks beneath, which consist of typical Franciscan sandstones, shales, cherts, and basalts. At only one point on the base has glaucophane schist been developed but practically all of the thin remnant above has been converted into schist; the planes of schistosity parallel the contacts of the sill and the bedding of the sediments beneath. Schists are also developed from leaves included within the serpentine and on the margins of small plugs. Since this area illustrates several modes of occurrence of the schists a map and cross sections (Figs. 4 and 5) are presented showing the distribution of serpentine, schists, and unaltered Franciscan. The unaltered rocks consist of interbedded sandstones and shales, rhythmically bedded cherts, and basalt; these have not been differentiated on the map as their differentiation would obscure the schist-serpentine relationship. There is a heavy cover of soil and many slides in the area and contacts are obscured in some places. However, the distribution of serpentine and schist is readily determined. This area is 5 miles north of Angel Island where similar relations were described by Ransome.[86]

[86] F. L. Ransome, *op. cit.* (1894).

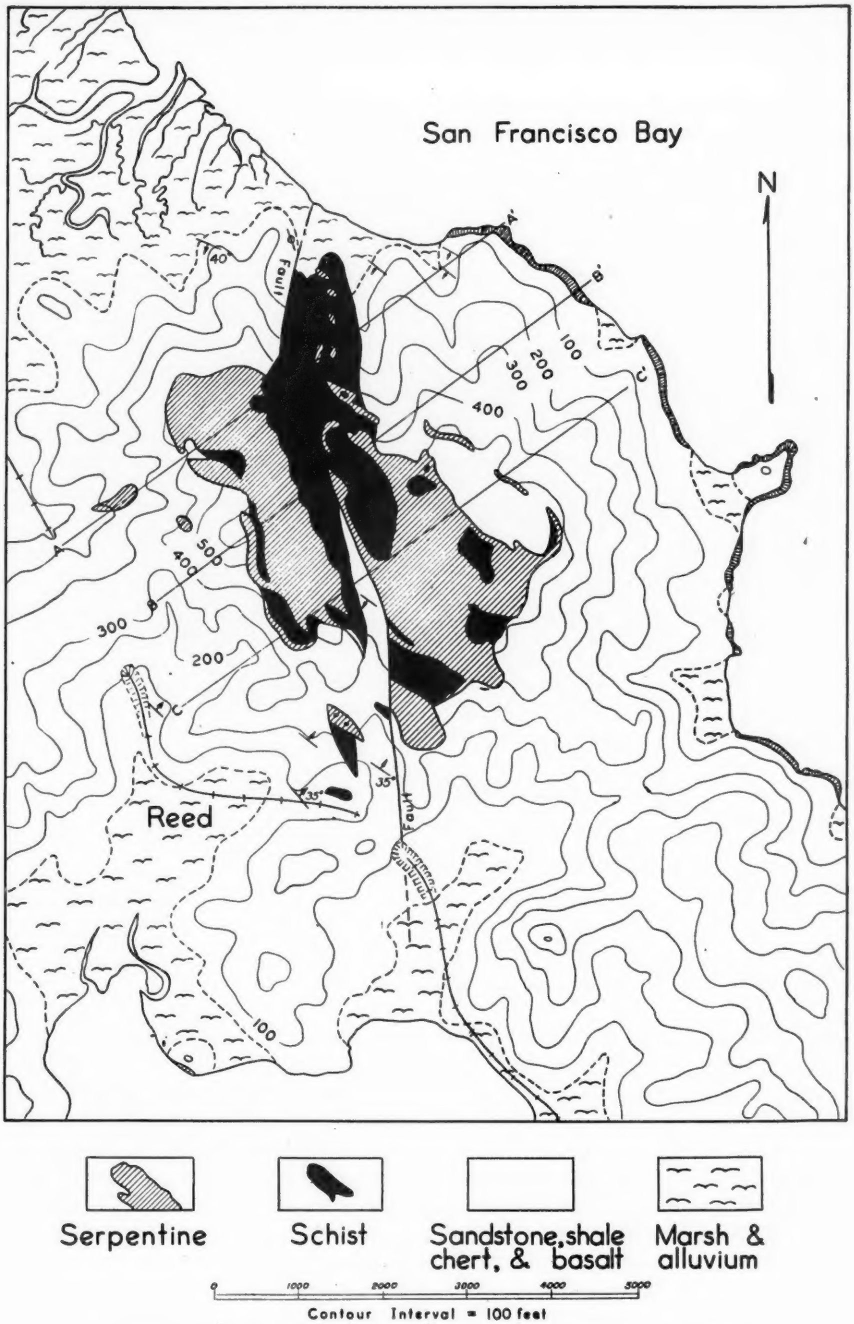


FIG. 4.—Geologic map of northern part of Tiburon Peninsula, showing relation of schist bodies to serpentine.

Several sills of serpentine occur in the Red Mountain region in southern San Benito County and here also the greatest development of schists is on the upper contact of the sills. Contact schists are not extensively developed in the Santa Lucia Range, but there are several examples of thin zones above sills.

Another excellent illustration of the localization of schists is found in the Petaluma Quadrangle on the ridge (highest point has an elevation of 1,179 feet) south of San Lucas Valley. Here the Franciscan consists of sandstones, shales,

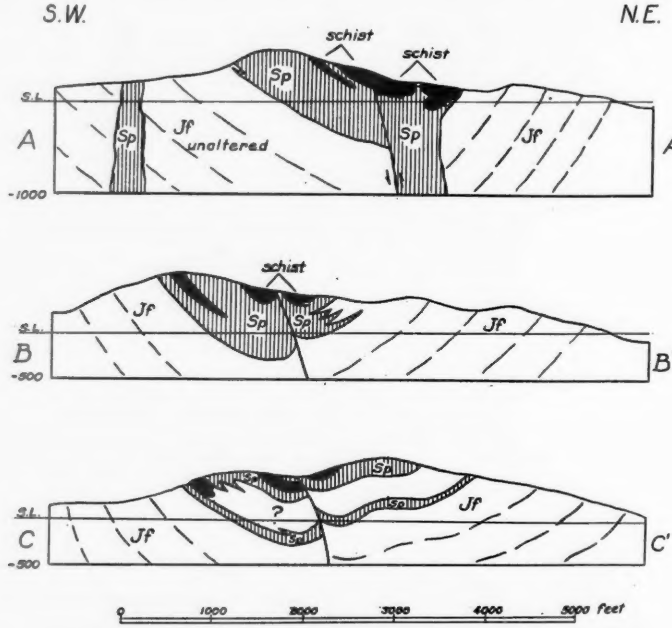


FIG. 5.—Cross sections, northern part of Tiburon Peninsula, showing relation of schist bodies to serpentine.

cherts, basic tuffs, pillow basalts, and basalt breccias. These are intruded by a sill-like body of serpentine; both the sediments and volcanics and the sill dip south. The sill lies on the north side of the ridge and the south slope is practically a dip slope of glaucophane and actinolite schist, lying on top of the sill. Although there are many minor contortions, the strike of the schist belt and the schistosity is parallel with both the sill and the attitude of the unaltered sediments. Just north of the crest of the ridge there is a zone of lightly metamorphosed sandstones and shales, now converted into rather fine-grained glaucophane schists in which the original bedding and alternations of sands and shales are clearly shown; the schistosity is typically parallel with the original bedding.

Many more examples could be given of the localization of schists on the upper

contact of sills. Those that have been given are readily accessible. The writer endeavors to cite examples that are accessible by road where possible.

There is great irregularity in the distribution of schists even above the sills. Some of the schist belts are continuous and coincident with the sill but more commonly the distribution is irregular and there are small areas of schist completely surrounded by unaltered sediments even on the upper side of the sill.

Included leaves of sediments are common in many sills; these either may show little sign of alteration or they may be completely converted into schists. In fact the degree of alteration may vary within the same inclusion, a part being com-

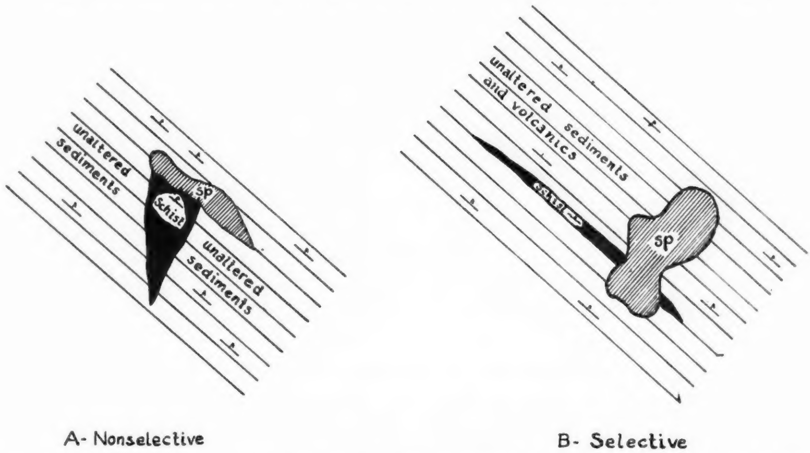


FIG. 6.—Sketches illustrating non-selective and selective types of alteration of Franciscan rocks into glaucophane schists. Based on actual occurrences.

pletely schistose and a part only baked; this type of variation may take place either across or parallel with the bedding.

Schists are also formed on the margins of plugs either as scattered areas on the contact or as tongues extending away from the intrusion. Two types of schist tongues occur, one in which the schist area cuts across the trend of the rocks (both sediments and volcanics) and the other where certain beds, ordinarily sandstones, are rendered schistose and appear inclosed in and parallel with the bedding of unaltered sediments. These may be called non-selective and selective types of alteration. Actual occurrences of both types are shown in Figure 6. Non-selective alteration is commoner than selective.

Non-selective alteration is defined as the development of schists from various types of sediments and volcanics in an area which extends away from the intrusive contact into unaltered rocks or which may appear as an isolated schist mass in the midst of unaltered sediments and volcanics. Although the planes of schistosity are parallel with the original bedding, and the bedding of the adjacent sediments, the schist body may lie at any angle to the attitude of the surrounding

rocks. Selective alteration is defined as the alteration of a particular bed, in general a sandstone, which extends away from the intrusion and is parallel with the bedding of the inclosing rocks. It presents the peculiar appearance of a thoroughly schistose rock interbedded with unaltered sediments. In non-selective alteration the volatiles and solutions that caused the metamorphism of the rocks spread outward from some point on the contact and altered various kinds of sediments and volcanics in an area of varying size. With selective alteration the volatiles and solutions from the intrusive spread outward along a particular bed, generally a sandstone, possibly because of greater permeability.

The best examples of selective alteration known to the writer occur in the southern part of the Santa Lucia Range, San Simeon Quadrangle, on the ridge west of Burnett Creek. As mentioned previously, schists occur interbedded with unaltered sediments and volcanics, sandstones, shales, conglomerates, cherts, and basalts. The schists are present as comparatively thin layers, having the normal thickness of the individual sedimentary beds; both the layers and the schistosity within them parallel the bedding of the inclosing rocks. Several such schist layers occur and at one place, near the crest of the ridge, the relations are clear. A small plug, with an exposure of about 200 by 300 feet, intrudes the sediments; extending for at least 1,000 feet northwesterly from the contact is a thin schist layer developed from a sandstone and inclosed in unaltered sandstones, cherts, and shales. On the southwest side of the plug is a very small area of schists of the non-selective type.

A few small areas of glaucophane and related schists occur as isolated areas in the midst of unaltered sediments and without any visible connection with basic or ultrabasic intrusives. However, they occur in regions in which serpentine intrusions are common and are regarded as non-selective tongues developed above unexposed intrusives. The two best and most accessible occurrences of this nature are in Hospital Canyon, Carbona Quadrangle, about 2,000 feet north of the mouth of Buckeye Gulch and in the Lakeport Quadrangle, east of Clear Lake, on the road from Lucerne to Bartlett Springs and at an elevation of approximately 2,700 feet. Both of these are small areas less than 200 feet in diameter and lie in the midst of unaltered sediments, chiefly sandstones and shales. In both places the schistosity is parallel with the bedding of the surrounding sediments, except for the minor crenulations that are nearly everywhere present. The Lake County area is only lightly metamorphosed and the original beds of shale and sandstone are clearly discernible in alternate layers of fine- and medium-grained glaucophane schist which have the same thickness as the shale and sand layers in the unaltered rocks.

Another excellent example of an isolated schist area has been described and mapped by Wilson[87] in the eastern part of the San Benito Quadrangle. This

[87] Ivan F. Wilson, "Geology of the San Benito Quadrangle," doctor's dissertation, University of California, Department of Geological Sciences, 1942.

area is approximately one mile in diameter and has no visible connection with an intrusive; serpentines, however, are exposed both on the east and west. Regarding the relation of schistosity and bedding, Wilson states:

> A syncline in the Franciscan sediments north of Tres Pinos Creek may be traced uninterruptedly through a belt of glaucophane schists, in which its presence is indicated by the planes of schistosity.

Only rarely is it possible to trace an unaltered sediment or volcanic directly into a thoroughly recrystallized schist. This is due to several causes, chief of which is the greater resistance of the schists. Ordinarily they stand out as small knobs rising above strongly weathered and poorly exposed sediments or they are separated from the unaltered sediments by erosional moats. Since the formation of the schists the Franciscan has undergone several severe diastrophisms and the sediments in many places have been crushed and battered against the more resistant schist bodies. Nevertheless, examples are known where unaltered sediments may be traced directly and continuously into schists. Nearly all stages may be observed and studied under the microcsope. The changes that take place are briefly described later.

Some glaucophane schists have another mode of occurrence that has no relation to their origin. A misconception regarding the origin of the schists appears to have arisen through the presence of schist and serpentine here and there along certain fault zones between the Franciscan and younger rocks and it has been thought by some that there is a connection between the faulting and the development of the schists. However, the presence of schists along faults is either quite fortuitous or due to the tendency of the plastic serpentine to squeeze upward along faults, carrying with it sandstones, cherts, and volcanics, as well as schists. Schists are only rarely present along faults. An excellent example is the thrust fault between Franciscan and Cretaceous along the east side of the Diablo Range. In the 55-mile stretch between Hospital Canyon and Panoche Creek schists are present in only two widely separated localities along this fault, Hospital Canyon and south of Ortigalito Creek.

From observations made by the writer and others throughout the Coast Ranges of both California and Oregon, it may be stated definitely that by far the greater number of occurrences of glaucophane and related schists are on the borders of basic and ultrabasic rocks or as leaves within intrusions. Even where there is no direct surface connection intrusives are exposed in the same general area.

The schists occur in small areas and pass within a short distance into unaltered sediments; nearly all stages in alteration may be observed. The planes of schistosity are parallel with the original bedding and in many places the original alternations of sandstone and shale are recognizable even in thoroughly recrystallized schists. Where rhythmically bedded cherts and shales have been altered the distinction between the two is everywhere clear even though recrystallization has

been complete. The cherts are converted into granulose rocks generally without noticeable directional arrangement of the new-formed minerals; the shales pass into fine-grained schists with strong directional arrangement parallel with the bedding. The planes of schistosity, where present, are not the result of directed pressure, but of the permeation of volatiles and solutions along bedding planes. Structural features of the unaltered sediments pass into and through schist bodies and are reflected in the planes of schistosity. The schist areas were folded with the sediments.

The schists do not surround the intrusives as a continuous contact aureole, but have a very erratic distribution, occurring here and there as irregular, discontinuous patches. Even on the tops of sills, where the closest approach to regularity of distribution is attained, the distribution is in many places erratic and patches of schist may be included within unaltered sediments.

From the evidence that has been presented it is clear that the schists are not the result of regional dynamic or dynamo-thermal metamorphism and it is equally clear that they are not the result of normal contact action. Their mode of occurrence and their character (which are described later) stamp them as the result of local pneumatolytic or additive metamorphism, accomplished by emanations from basic and ultrabasic intrusives.

Not all intrusives are accompanied by the development of schists nor is the size of an intrusion any measure of the volume of schists developed; there are numerous examples of sills, plugs, and dikes that have only baked and slightly veined the adjacent sediments (the first stage in schist formation) without causing the actual development of schists. Fairly large areas of schists may be formed here and there at the contact of large intrusions but equally large, or even larger schist areas may result from very small intrusives, or at least intrusives with small surface exposures. The great Burro Mountain plug, previously described, produced no schists on its borders but small plugs, with diameters of only a few hundred feet, may cause the extensive development of schists. The large and thick sills in the southern part of the Santa Lucia Range have caused little alteration of the rocks into which they were intruded. On the other hand, there are many examples of the formation of schists on the upper surface of small sills. The volume of schists formed is not a function of the size of the intrusive, but of the quantity of volatiles and solutions accompanying and escaping from the magma during and after its emplacement.

Intrusions which rose to a high level in the Franciscan-Knoxville series, and most of which are very large, accomplished little in the way of schist development. It is believed that the great thickness of some of the sills high in the section is due to the greater ease of spreading beneath a comparatively thin prism of sediments than was possible for sills which were emplaced at a lower horizon and beneath a great thickness of sediments and volcanics. It is also believed that the volatiles and solutions accompanying sills emplaced at high levels had been largely

used up in the complete serpentinization of the ultrabasic rocks. There is reasonably good evidence that, in some places, serpentinization may have been complete, or nearly so, before final emplacement.

Thus far, only the exomorphic effects have been mentioned. In places there are noticeable endomorphic effects and the serpentines near the contact have been converted into basic schists. These effects are discussed later.

Definitions of terms.—The word "schist" has been used throughout the preceding discussion, but not all the rocks so designated are schistose. In fact the term "schist" applied to these rocks is most unfortunate since, to many, it implies a type and degree of metamorphism that is inconsistent with the facts. It is realized that some other term, such as "pneumatolytes," perhaps, would be more descriptive and a better indication of the origin of the rocks but, since the writer does not desire to introduce new terms into an already overburdened literature, and since these rocks have been called "schists" for 75 years, it is, perhaps, as well to continue a practice sanctioned by long use. As long as the sense in which the word is used is understood its use is defensible. The writer will use the term "schist" for those recrystallized rocks which have a directional arrangement brought about by the presence of either prismatic or platy minerals. Such rocks may be either nematoblastic or lepidoblastic, depending on the relative amounts of prismatic or tabular minerals present.

However, many of the thoroughly recrystallized rocks have no directional arrangement of their components. This lack of schistosity is not necessarily due to a preponderance of equidimensional minerals such as quartz, albite, and garnet, but is largely dependent upon the original nature of the rock. Rocks without original bedding or directional arrangement, such as massive sandstones, cherts, basalts, and other massive igneous rocks, yield non-schistose products, even though thoroughly recrystallized and largely made up of prismatic and, or, tabular minerals. These non-schistose rocks have a texture very similar to that of the granulites, but since the term granulite signifies a very advanced stage of metamorphism, it is not applicable to them. Several terms have been used to describe these non-schistose Franciscan metamorphics, such as eclogite, gneiss, pseudodiorite, pseudodiabase, amphibolite, and "— rock." Since none of these is satisfactory except "— rock" this is used (quartz-albite-glaucophane rock) for the non-schistose varieties.

Minerals of Franciscan metamorphics.—Approximately 40 minerals have been reported from the Franciscan metamorphics; of these more than 30 have been reported in several occurrences. Thirty different minerals have been observed by the writer, not counting those that occur in veins in the schists, such as benitoite, neptunite, joaquinite, natrolite and other zeolites, and various copper minerals. The following is a list of the minerals, other than those universally occurring in veins, that are of rather common occurrence as constituents of the pneumatolytic metamorphics.

Actinolite	Diallage	Oligoclase
Albite	Epidote	Pargasite
Apatite	Garnet	Pyrite
Biotite	Gastaldite	Quartz
Calcite	Glaucophane	Rutile
Chlorite (many varieties)	Jadeite	Sericite
Clinozoisite	Lawsonite	Sphene
Crocidolite	Leucoxene	Talc
Crossite	Magnetite	Zircon
Diopside	Muscovite	Zoisite

Most of these minerals have resulted from the pneumatolytic metamorphism but some are relics and some appear to be due to retrograde metamorphism. Quartz is both a new formed and a relic mineral; apatite, diallage, zircon, and perhaps oligoclase appear to be relic minerals; some of the chlorites and leucoxene are probably retrograde products. The following minerals also commonly occur in veins cutting the schists (and in some places the adjacent rocks) as well as normal constituents of the schists: albite, calcite, chlorite, garnet, glaucophane, lawsonite, quartz, and sphene.

Apparently a fairly common belief is that actinolite results from the metamorphism of basic igneous rocks. It is, perhaps, more common in the basic schists, but it is also common in the quartz-albite-glaucophane-actinolite schists developed from arkose sandstones. It is not as common as glaucophane, but it has a wide range of occurrence, being formed in basic, intermediate, and moderately quartz-rich schists; it has not been observed by the writer in the quartz rocks derived from cherts. Several types of actinolite occur and, probably, a fairly wide range in chemical composition is represented. The commonest type has about the same general habit as the glaucophane and occurs as poorly formed prismatic crystals, or as fibers, or bundles of fibers. No analyses have been made of this type. Another variety occurs as well formed, commonly translucent, light to dark green crystals, some of them several centimeters in length, associated with talc, chlorite, and rutile, in very basic schists. Analyses of this variety show it to be soda-bearing; its significance is discussed later.

Albite is very common both in the schists and veins; it is both twinned and untwinned. In altered arkose sandstones and basic igneous rocks probably much of the albite resulted from the dissociation of the plagioclase into the albite and anorthite molecules resulting in clear grains of albite and a variety of minerals such as zoisite, lawsonite, epidote, and garnet, depending on the composition of the original plagioclase and the character of the adjacent material with which reactions might take place. However, a part of the albite appears to have resulted from the actual introduction of soda from the magma. This is probably the explanation for the albite in the quartz-albite-glaucophane rocks derived from cherts.

Apatite is not uncommon, but it forms less than 1 per cent of the rocks, it has about the same percentage and mode of occurrence (as minute prismatic inclusions in other minerals) as in the original sandstones. There is no convincing evidence for the introduction of P_2O_5.

Biotite is moderately common in the metamorphics, particularly those derived from shales, cherts, and arkose sandstones. It is not, however, everywhere present in these rocks. Undoubtedly there was sufficient potash in the original sandstones and shales to account for the biotite, but not in the cherts. The presence of biotite in quartz-glaucophane-biotite rocks derived from cherts indicates the introduction of potash as well as soda.

Various types of chlorites occur in both low- and high-silica schists, but they are most abundant in those derived from serpentine and basic igneous rocks. Clinochlore, penninite, prochlorite, and other less certain varieties may be recognized. In the more basic schists chlorite appears to have been formed at an early stage; it could develop readily from serpentinized olivine or rhombic pyroxene by the addition of alumina. In many cases chlorite has resulted from other minerals, probably by retrograde metamorphism. Garnets are commonly surrounded by a halo of pale to deep green chlorite. Only one analysis of chlorite from the Franciscan metamorphics is known.[88]

Clinozoisite, zoisite, and epidote are abundant in some of the schists, especially in those low in silica. Where abundant, these minerals indicate the introduction of lime and alumina.

Although garnets are widespread in the schists and may occur in practically all types from the most basic to the very quartz-rich rocks, they are not everywhere present, since they appear to be one of the last minerals to form and occur only in thoroughly recrystallized schists. In places they make up as much as 25 or 30 per cent of certain schists, but ordinarily they are not so abundant. The garnets are red to red brown in color and most of them occur as dodecahedral porphyroblasts; some occur as anhedral grains or aggregates of grains. The size ranges from microscopic grains to crystals more than a centimeter in diameter; the size in any particular rock is generally uniform. As previously mentioned, they are not uncommonly surrounded by, or even completely replaced by, chlorite and white mica. The chemical composition has been investigated by Pabst[89] who, on the basis of four analyses of garnets from widely spaced localities, concluded that they have a reasonably constant composition. The four analyses indicate that the almandite molecule makes up about 50 per cent, the remainder being grossularite, andradite, and pyrope molecules in nearly equal proportions. It is not believed that the garnets indicate the further addition of material from the intrusive but simply recombination of materials present in the original rock, or introduced in an early stage of recrystallization.

Glaucophane, or one of its varieties, is probably the most characteristic mineral present in the Franciscan metamorphics. So common is it that the term "glaucophane schists" has been used as a general term for these rocks although there are varieties in which glaucophane is scarce or even absent. Unless masked

[88] W. C. Blasdale, "Contribution to the Mineralogy of California," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 2 (1901), pp. 327–48.

[89] Adolf Pabst, "The Garnets in the Glaucophane Schists of California," *Amer. Mineralogist*, Vol. 16 (1931), pp. 327–33.

by more abundant darker-colored minerals, it imparts a blue-gray, blue, or bluish black color to the rocks, depending on its color and abundance. It ordinarily occurs as poorly bounded prismatic crystals, as irregular grains, or as radiating fibers or bundles of fibers. Some specimens are well bounded by crystal faces and may attain a length of several centimeters, especially where occurring in granulose quartz or quartz-albite rocks derived from cherts. It occurs in very small irregular veins, especially in partly altered dense basalts.

Glaucophane not only occurs in distinct individual crystals, but also as tips or rims on other amphiboles, such as actinolite or pargasite; the tips and rims are in optical continuity with the green amphibole.

A sufficient number of analyses have not been made to establish varieties on the basis of chemical composition. There is a wide range in the intensity of the characteristic pleochroism that may reflect a fairly wide range in chemical composition. Ordinarily the pleochroism is strong with X, pale yellow to greenish yellow, Y, deep violet, and Z, azure blue to ultramarine blue, but there are varieties with very faint pleochroism, ranging from almost colorless or pale straw yellow to faint shades of violet and blue. The faintly pleochroic variety is regarded as gastaldite, an iron-poor glaucophane. The variety crossite differs from glaucophane in the position of the optic axial plane. The one analysis of crossite also indicates that there is a chemical difference. However, additional analyses of glaucophane might show that the chemical composition of crossite lay within the range of variation of ordinary glaucophane.

The composition of glaucophane and crossite in the Franciscan is shown in Table V; analyses of glaucophane from Greece and gastaldite from Italy are given for comparison.

TABLE V

ANALYSES OF GLAUCOPHANE

	I *Glaucophane*	*II* *Glaucophane*	*III* *Crossite*	*IV* *Glaucophane*	*V* *Glaucophane*	*VI* *Gastaldite*
SiO_2	52.39	54.52	55.02	55.64	57.67	58.55
Al_2O_3	11.29	9.25	4.75	15.11	11.07	21.40
Fe_2O_3	3.74	4.44	10.91	3.08	3.20	—
FeO	9.13	9.81	9.45	6.85	9.68	9.04
MgO	11.37	10.33	9.30	7.80	9.85	3.92
CaO	3.03	1.98	2.38	2.40	0.95	2.03
Na_2O	6.14	7.56	7.62	9.34	6.80	4.77
K_2O	Tr	0.16	0.27	—	0.42	—
MnO	Tr	0.46	Tr	0.56	0.06	—
H_2O	2.57	1.78	—	—	0.48	—
TiO_2	0.14	0.39	—	—	—	—
	99.80	100.68	99.70	100.78	100.18	99.71

I. Glaucophane from Berkeley, California. W. C. Blasdale, analyst. *Univ. California Pub., Bull. Dept. Geol.*, Vol. 2 (1901), p. 338.
II. Glaucophane from San Pablo, California. W. C. Blasdale, analyst. *Ibid.*
III. Crossite from Berkeley, California. W. S. T. Smith, analyst. In C. Palache, *ibid.*, Vol. 1 (1894), p. 188.
IV. Glaucophane from Syra, Greece. O. Luedecke, analyst. *Zeitschr. Deutsch. Geol. Gesell.*, Vol. 28, p. 249.
V. Glaucophane from Syra, Greece. H. S. Washington, analyst. *Amer. Jour. Sci.*, 4th Ser., Vol. 11 (1901), p. 40.
VI. Gastaldite from St. Marcel, Italy. Alfonso Cossa, analyst. *Accad. Linc. Rom.*, Vol. 2 (1875), p. 33.

A sufficient amount of soda would be released by the dissociation of the albite molecule in the acid plagioclase of the ordinary arkose sandstone of the Fran-

ciscan to form some glaucophane without the addition of soda from the magma. Excess of soda over the other necessary constituents would unite with alumina and silica to form albite. However, there is not, as a rule, sufficient magnesia in the ordinary arkose sandstone for the formation of the same amount of glaucophane and therefore it would be necessary to introduce magnesia from the intrusive. The abundant development of glaucophane in quartz-glaucophane or quartz-albite-glaucophane rocks derived from cherts would require the introduction of several per cent of magnesia and soda and a small amount of alumina. Sufficient iron oxide is present in both the cherts and the sandstones for the formation of glaucophane or its varieties.

Lawsonite, like glaucophane, is a very characteristic mineral of the Franciscan schists. However, since it typically occurs in small grains and is without the distinctive color of glaucophane it is commonly difficult to detect on megascopic examination. This mineral occurs in two ways, as colorless to pale blue euhedral to anhedral grains ranging from microscopic size to several centimeters and as veins in the schists. Large, well formed crystals of lawsonite occur in the northern part of the Tiburon Peninsula, east of Reed Station, from where it was originally described,[90] and in Mendocino County, near Dos Rios. Aside from these two localities, where it occurs both in veins and as grains through the schists, it ordinarily occurs in small, scattered crystals. It is associated with glaucophane in soda schists, not only in California, but other parts of the world. Lawsonite is found in basic, intermediate and quartz-rich schists; it occurs sparingly in quartz-rich schists derived from cherts, being more abundant in those derived from basalts and sandstones.

The chemical composition appears to be constant, the slight variations probably being due to the presence of minute inclusions of other minerals. Its composition is represented by the formula, $CaAl_2Si_2O_8 \cdot 2H_2O$; in other words, it has the composition of the basic lime-plagioclase anorthite, plus two molecules of water. This led Smith[91] to state that the source of the lime must have been the plagioclase feldspar in the original igneous rocks and arkose sandstones from which the lawsonite-glaucophane schists were derived. He believed that the released anorthite molecule simply took up water and crystallized as lawsonite; however, the formation of lawsonite can not be explained so simply. It is possible that the source of a small part of the lime entering into lawsonite may have been the lime released by the dissociation of the plagioclase, but it is believed that the greater part was introduced from the basic and ultrabasic intrusives. Although plagioclase is abundant in the arkose sandstones it is rarely more basic than andesine and is ordinarily the lime-poor variety oligoclase or oligoclase-andesine. Analyses of the lawsonite-bearing schists show them to be considerably higher in lime than the arkose sandstones from which they were derived. The rocks sur-

[90] F. L. Ransome, "On Lawsonite, a New Rock-Forming Mineral from the Tiburon Peninsula, Marin County, California," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1 (1895), pp. 301–12.

[91] J. P. Smith, "The Paragenesis of the Minerals in the Glaucophane-Bearing Rocks of California," *Proc. Amer. Phil. Soc.*, Vol. 45 (1906), p. 197.

rounding many basic and ultrabasic intrusives, even where no recrystallized contact rocks are developed, are commonly greatly veined with calcite and quartz. There appears to be abundant evidence that, in some instances, a considerable amount of lime was given off by the magmas.

The amphibole listed as pargasite probably has a fairly wide range in composition. It is an aluminous amphibole darker in color and with stronger pleochroism than actinolite and the optical properties and indices of refraction are those of that part of the amphibole series embraced under pargasite and serve to differentiate it from green hornblende and actinolite. Like the actinolite it is in places rimmed or tipped with glaucophane. Pargasite is commonly associated with zoisite, epidote, chlorite, rutile, and garnet.

Schists containing abundant pargasite do not occur in extensive layers, but in rather small irregular or nodular masses associated with other schists or in the serpentine. Such schists appear to have been derived from basic igneous rocks or serpentines. They are described later.

A chemical analysis of pargasite from the Coast Range schists, and two analyses of actinolite are here given.

TABLE VI

ANALYSES OF PARGASITE AND ACTINOLITE

	I *Pargasite*	*II* *Actinolite*	*III* *Actinolite*
SiO_2	42.68	55.21	55.56
Al_2O_3	9.96	3.45	2.05
Fe_2O_3	6.12	7.49	5.97
FeO	12.25		
MgO	9.58	18.97	19.45
CaO	11.83	10.50	12.13
Na_2O	3.30	2.45	1.94
K_2O	0.89	—	0.30
H_2O+	3.16	1.75	2.58
H_2O-	0.12		
TiO_2	0.68		
	100.57	99.82	99.98

I. Pargasite from basic pargasite sch st, Arroyo Hondo, northern part of Calveras Valley, Santa Clara County, California W. O. Clark, analyst. In J. P. Smith, *Proc. Amer. Phil. Soc.*, Vol. 45 (1906), p. 191.
II. Actinolite, Berkeley, California. W. C. Blasdale, analyst. *Univ. California Pub., Bull. Dept. Geol.*, Vol. 2 (1901), p. 333.
III. Actinolite, San Pablo, California. W. C. Blasdale, analyst. *Ibid.*

Several other varities of the amphibole group, such as carinthine, smaragdite, and the iron-rich katoforite, have been reported in the Franciscan metamorphics, but their presence has not been verified. Detailed petrographic and chemical work undoubtedly would reveal the existence of a number of varieties of amphiboles, but for the present it is sufficient to include them under the three main types, glaucophane, actinolite, and pargasite.

Sphene and rutile are very common as accessory minerals in nearly all types of Franciscan schists. Rutile is commoner than sphene in the basic schists and sphene more abundant in the acid schists; both may occur in the same rock, however. Rutile ordinarily occurs in minute euhedral prisms, but rarely the crystals may be as much as a centimeter in length. Sphene occurs as anhedral

cloudy grains and as well faced euhedral crystals. It also occurs as small veins and as irregular aggregates of crystals up to 2 or 3 inches in diameter. Its color is ordinarily red-brown to honey-yellow, but it is pink to rose red and rarely brownish yellow. The causes of the variation in color have not been investigated.

A part of the sphene may be relic, especially in those schists derived from sandstones that already contain the mineral. Smith stated that the source of the titania was from the titaniferous hornblendes and pyroxenes in the original igneous rocks, released by dissociation of these minerals under metamorphism. This may be the source of some of the rutile and sphene in the basic schists, but obviously not in those developed from sandstones and cherts. The average content of titania in the schists, from published chemical analyses, is a little more than 1 per cent, which is slightly higher than in the average sandstone. Ordinarily titania does not appear to have been added during metamorphism, except in minute quantities, but the veins and large patches of sphene indicate that occasionally it was introduced.

Quartz is, generally, a relic mineral that has been recrystallized. This is clear in both the sandstones and cherts where stages in the recrystallization may be traced. The small amount of quartz present in some of the more basic schists may have been introduced, or have resulted in, the dissociation of the ferromagnesian minerals, as suggested by Smith. In some cases there is clear evidence that some silica was introduced during metamorphism. Quartz veins in the rocks adjacent to intrusives may indicate introduction although the silica may have resulted from the leaching of sandstones in the vicinity.

Zircon occurs in minute crystals, but it is comparatively rare; it is of the same order of abundance and size as in the original sandstones and regarded as a relic mineral. There is no evidence indicating the introduction of zirconia.

As a summary, it may be stated that a consideration of the minerals present and their relative abundance indicates that certain substances were introduced during metamorphism, a conclusion confirmed by a study of various types of schists whose derivation is known. Substances clearly introduced are soda, magnesia, alumina, and lime; varying but small amounts of silica, titania, and potash appear to have been added in some instances. Not all of these substances were introduced in every case; sometimes little or nothing was added, but at other contacts soda and magnesia seem to have been the chief substances while in other instances alumina or lime was introduced. Water appears to have been added in all instances.

Types of pneumatolytic contact rocks.—Because of the great variation in character of the original rocks and the different substances introduced from the magmas bewildering varieties of schist have resulted. The new minerals formed are so numerous, the possible combinations are almost unlimited. Even when one commences with the same original sediment very different products result according to the substances added, the order in which they were added, and the minerals formed. It is not yet possible to make a classification of the Franciscan

metamorphics that will take into account all of the complex factors involved. A list of the varieties that have been reported would occupy many pages.

A convenient division of the Franciscan metamorphics is into those high in quartz and without albite, those containing varying proportions of both quartz and albite, and those without either quartz or albite. The following list is not all-inclusive, but it gives the chief types. Garnet, sphene, and rutile may be present in any of these types. They are omitted from the list for the sake of simplicity.

TYPES OF FRANCISCAN METAMORPHICS

Quartz rocks and schists (quartz predominant)
- Quartz-glaucophane
- Quartz-glaucophane-lawsonite
- Quartz-glaucophane-muscovite-chlorite
- Quartz-crocidolite

Quartz-albite rocks and schists
(All variations between proportions of quartz and albite)
- Quartz-albite-glaucophane
- Quartz-albite-glaucophane-muscovite
- Quartz-albite-glaucophane-actinolite
- Quartz-albite-glaucophane-lawsonite
- Quartz-albite-glaucophane-lawsonite-jadeite
- Quartz-albite-glaucophane-biotite
- Quartz-albite-biotite-muscovite (rare)
- Quartz-albite-glaucophane-epidote

Albite schists and rocks
- Albite-glaucophane
- Albite-actinolite
- Albite-glaucophane-actinolite
- Albite-glaucophane-epidote-zoisite
- Albite-glaucophane-muscovite
- Albite-glaucophane-lawsonite
- Albite-glaucophane-lawsonite-zoisite
- Albite-glaucophane-actinolite-clinozoisite
- Albite-actinolite-chlorite-epidote
- Albite-crossite

Glaucophane schists and rocks (no quartz or albite)
- Glaucophane-lawsonite
- Glaucophane-lawsonite-chlorite
- Glaucophane-chlorite-epidote
- Glaucophane-actinolite-zoisite
- Glaucophane-epidote
- Glaucophane-epidote-zoisite

Actinolite schists and rocks
- Actinolite-glaucophane
- Actinolite-glaucophane-chlorite-zoisite
- Actinolite-chlorite
- Actinolite-chlorite-zoisite
- Actinolite-talc
- Actinolite-talc-chlorite

Pargasite schists and rocks
- Pargasite-chlorite
- Pargasite-zoisite-clinozoisite
- Pargasite-zoisite-talc
- Pargasite-glaucophane-talc
- Pargasite-glaucophane-zoisite-epidote-talc

The writer has no intention of describing the various schists, many of which are only minor varieties. Rather, he describes certain types of known derivation and the stages through which they have passed.

The passage of rhythmically bedded cherts and shales into schists and rocks affords clear and convincing example of the progressive alteration of an original sediment into a thoroughly recrystallized rock. Although the resultant rocks may be diverse the process is similar and the original rhythmic bedding is preserved.

The pneumatolytic metamorphism that caused the alteration very probably began when the cherts were largely opaline. However, depth of burial and folding have caused a mild, but universal recrystallization. Ordinarily, the cherts, either red or green, are made up of an exceedingly fine mosaic of chalcedony or quartz through which the original coloring matter, either ferrous or ferric iron, is evenly distributed. In some, there is a faint dispersion banding in the individual chert layers caused by a slight segregation of clayey impurities. In some, depth of burial and folding has caused the development of very minute granules and short needles of a mineral that appears to be zoisite. Radiolaria stand out as small clear uncolored areas; the structure of some forms is well preserved even though slight recrystallization has taken place. Minute veinlets of quartz are abundant even at a distance from contacts.

Several different types of contact alteration may be recognized, according to the intensity of metamorphism and whether due simply to heat or to material added. The simple heat change, commonly on intrusive basalt contacts, has been described by Davis.[92] This ordinarily results in an obliteration of the rhythmic bedding and an increase in color to bright shades of vermillion and orange. The chert becomes spherulitic and there is a tendency toward the aggregation of iron oxides toward centers. Occasionally needles or small veinlets of glaucophane may develop. A more distinctive change resulting in more complete alteration, takes place on serpentine, or serpentine-gabbro contacts, the first visible result being a loss, rather than an intensification, of color and the beginning of recrystallization. The fine mosaic becomes coarser and the coloring matter, originally evenly distributed, changes into magnetite (or magnetite and hematite) and occurs between the growing grains of quartz. Radiolarian remains lose their outline, but some are still visible even at an advanced stage of metamorphism. The original veins have become more coarsely crystalline and new quartz veins, or lenticular areas develop parallel with the bedding. Commonly at this stage fine needles of glaucophane form in the interbedded shales. Some become abundant and the shales pass into rather thoroughly recrystallized fine-grained glaucophane schists before any new minerals, other than quartz and magnetite, have formed in the dense cherts. Alteration may stop at this stage, resulting in alternating bands of

[92] E. F. Davis, "The Radiolarian Cherts of the Franciscan Group," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11 (1918), pp. 270–74.

fine-grained light to dark blue glaucophane schist and white or gray recrystallized chert in which the remains of radiolaria may be visible. The demarcation between chert and schist is as sharp and clear as before alteration.

With a greater addition of substances from the magma, glaucophane needles begin to form throughout the chert and the chert passes into a granular quartz-glaucophane rock. Typically there is no definite orientation of the glaucophane, the prisms being arranged at random, but in some prisms the long axes are parallel with the original bedding. On the northern end of the Tiburon Peninsula this change may be observed in several places; here very minute garnets have formed in addition to glaucophane, and are arranged in bands in the chert, probably developed from slightly impure diffusion bands in the original chert. If a sufficient quantity of soda is introduced, albite may form and the chert becomes a granular quartz-albite-glaucophane rock, sometimes with small amounts of garnet, sphene, and magnetite.

An interesting rock developed from a chert has been described by Mielenz[93] from the Red Mountain region, southern San Benito County. This is a quartz-albite-jadeite-muscovite-glaucophane-lawsonite rock with the following mineral composition.

Minerals	*Per Cent*	*Minerals*	*Per Cent*
Quartz	65	Lawsonite	3
Albite	10	Garnet	2
Jadeite	10	Sphene and magnetite	2
Muscovite	5		—
Glaucophane	3		100

A slight schistosity is imparted to the rock by the muscovite and by slightly granulated quartz bands. The jadeite and glaucophane occur in radiating prisms, in places intergrown, but both may occur in independent areas. The albite is both twinned and untwinned and occurs as anhedral grains in the quartz mosaic. The lawsonite is in idioblastic crystals of about the same size as the quartz and albite. The garnet is generally surrounded by a halo of chlorite.

From the mineral composition estimated by Mielenz, the writer has calculated the chemical composition of the rock. This is given in Table VII, together with analyses of unaltered Franciscan cherts and quartz-glaucophane rocks derived from cherts.

Although there are only three analyses of Franciscan cherts, and only two chemical and one computed analyses of glaucophane rocks derived from cherts it is believed that these are sufficiently representative and consistent for comparison and that they clearly indicate that there has been an introduction of material. The most consistent increase is in alumina, which averages more than 5 per cent; the increase in soda, although constant, is not as consistent, ranging from less than 1 to more than 5.5 per cent and averaging 3 per cent. Lime has increased on the average a little less than 1 per cent. Magnesia and iron oxide have increased

[93] R. C. Mielenz, "Geology of the Southwestern Part of San Benito County, California," unpublished doctor's dissertation, University of California Library, 1936.

in two cases. It is possible that a slight increase in titania would be shown had a determination been made in each case as it is seldom that altered cherts are free from sphene. It is unlikely that the same substances were added at every contact where pneumatolysis took place; not only were there considerable variations in the substances added, but also in the amounts of individual substances. Variation in the amount of soda is indicated in the wide variation in the amount of glaucophane and albite developed in the recrystallized cherts.

TABLE VII

ANALYSES OF CHERTS AND QUARTZ-GLAUCOPHANE ROCKS

	I	II	III	IV	V	VI
	Unaltered Chert	*Unaltered Chert*	*Unaltered Chert*	*Quartz-Glaucophane Rock*	*Quartz-Glaucophane Rock*	*Quartz-Albite-Jadeite Rock (Calculated)*
SiO_2	93.54	95.08	96.37	82.53	80.21	83.07
Al_2O_3	2.26	2.17	2.38	6.88	7.99	8.91
Fe_2O_3	.48	2.82	1.70	0.59	—	0.94
FeO	.79			4.11	3.35	1.02
MgO	.66			1.86	1.54	0.43
CaO	.09			0.68	1.10	1.15
Na_2O	.37			1.21	5.97	2.83
K_2O	.51			1.24	0.22	0.59
H_2O	.93			1.42	0.74	0.65
TiO_2						0.41
MnO	.23					
	99.86	100.07	100.45	100.52	101.12	100.00

I. Brownish red chert from Bagley Cañon, Mount Diablo. W. H. Melville, analyst. *Bull. Geol. Soc. America*, Vol. 2 (1891), p. 411.
II. Red chert from Red Rock Island, San Francisco Bay. E. F. Davis, analyst. *Univ. California Pub., Bull. Dept. Geol.*, Vol. 11 (1918), p. 268.
III. Red chert from Point Richmond, San Francisco. E. F. Davis, analyst. *Ibid.*
IV. Quartz glaucophane rock, Four Mile Creek, Coos County, Oregon. H. S. Washington, analyst. *Amer. Jour. Sci.*, 4th Ser., Vol. 11 (1901), p. 55.
V. Quartz-albite-glaucophane rock derived from chert, Angel Island. F. L. Ransome, analyst. *Univ. California Pub., Bull. Dept. Geol.*, Vol. 1 (1894), p.231.
VI. Calculated chemical composition of a quartz-albite-glaucophane-jadeite rock described by Mielenz.

The writer considers that the conversion of Franciscan cherts into glaucophane-bearing rocks offers convincing proof of the introduction of material during metamorphism. The amount may not have been great in most cases, but it obviously would be impossible to form a glaucophane-bearing rock from an ordinary Franciscan chert without the introduction of some soda and alumina.

Smith,[94] however, concluded that no introduction of material, except water, had taken place and stated that all the changes could be explained by a chemical readjustment of substances already present. He believed that the chemical composition of the metamorphic was essentially that of the original rock. In a broad sense this may be true, but it is also true that, at least in the case of cherts, material has been added.

The chemical changes involved in the passage of sandstones and shales into schists are little known since there are no available analyses of schists unquestionably derived from sandstones. The silica content of the great bulk of the schists that have been analyzed is less than 50 per cent. If the analyses even

[94] I. P. Smith, *op. cit.* (1906), pp. 238–39.

roughly reflect the character of the original rock most of the schists that have been analyzed were derived from basalts or basic tuffs. More analyses will have to be made before a positive statement is possible.

The writer has not made a careful study of schists clearly derived from sandstones, but has made a few observations that should be recorded. Very commonly the development of schists from both sandstones and shales is preceded by veination and sometimes by hydrothermal alteration. In many instances alteration has stopped at this point and no true schists have been developed, the only sign of alteration being veination and perhaps a slight bleaching. In this process quartz, calcite, and even albite veins, commonly parallel with the bedding, become numerous and the feldspars are partly or wholly destroyed. If glaucophane is developed it appears to be localized in the areas occupied by the original feldspars and the interstitial material. At first the newly formed glaucophane and, or, actinolite occurs in very fine needles either in radiating groups or with a roughly parallel arrangement. Shale flakes tend to develop sericite and then muscovite. Original flakes of chlorite become better defined and epidote begins to form from the altered plagioclase. Poorly bounded cloudy grains of sphene also occur. At this stage the quartz begins to recrystallize. The final schist appears to result from a continuation of this process with the increase in size of the various constituents, especially the glaucophane and, or, actinolite and epidote.

In the shales the first changes noted are minute veination and the development of sericite and muscovite and very fine needles of glaucophane, ordinarily without orientation. The sandstones change color from dark gray to blue gray and finally to dark blue or green, according to the relative amounts of glaucophane and actinolite but the dark color of the shales is not lost until recrystallization is fairly complete. As stated previously, as the chemical changes are unknown; it is hoped that more complete information regarding these changes will be obtained by further investigation.

There is an especially striking and interesting schist that has been mentioned frequently, but which never has been analyzed or explained. This is largely made up of clear translucent light to dark green actinolite, or various percentages of actinolite, talc, and chlorite; small amounts of sphene, rutile, and garnet may be present. This type of rock, although common and widespread, occurs without exception in small nodular masses, rarely more than a few feet in length, either in serpentine or on the contact between serpentine and other schists. These small nodular masses have only a very crude schistosity which commonly nearly parallels the outer surface. In form and general appearance they are not unlike the sheared and nodular serpentine in which they so commonly occur. Rapid variation in grain size within the same nodule is common and large clear clusters of crystals of green actinolite pass abruptly into the fine-grained actinolite. If rather coarse-grained these rocks are rather friable and are readily crumbled with the fingers even though perfectly fresh and unweathered.

Although no analyses of this type are available it is possible to make rather

accurate computations of their chemical composition as there are a number of analyses of the individual minerals actually separated from rocks of this type. Several varieties are known, but the predominant mineral in each is actinolite. One common variety consists of about 75 per cent actinolite and 25 per cent talc; another of varying proportions of actinolite and chlorite. The computed chemical composition of two common varieties is as follows.

	Rock Made Up of 75 Per Cent Actinolite and 25 Per Cent Talc	*Rock Made Up of 60 Per Cent Actinolite and 40 Per Cent Chlorite*
SiO_2	55.54	44.28
Al_2O_3	4.30	12.05
Fe_2O_3 / F_2O	5.38	9.43
MgO	21.44	19.10
CaO	8.74	6.79
Na_2O	1.65	1.87
H_2O+	2.95	6.48
	100.00	100.00

Both from the chemical composition and mode of occurrence, basic alumina-poor-magnesian-rich rocks of this general type are believed to represent endomorphic effects and to have been formed from serpentine (or the original peridotite) by the addition of several substances. In order to form a rock made up of actinolite and talc from serpentine it would be necessary to introduce silica, a little alumina and soda, and a considerable amount of lime; to form a rock made up of actinolite and chlorite, it would be necessary to add a considerable amount of alumina and lime and a small amount of soda and silica. The same substances would be necessary in both cases, but in different proportions.

A somewhat similar basic recrystallized rock also occurs as small blocky masses in serpentine. This is dark, heavy, tough, non-schistose rock in which the chief minerals are pargasite and zoisite, with minor amounts of epidote, clinozoisite, rutile, garnet, talc, chlorite, and glaucophane. Since analyses of both pargasite and zoisite from the Franciscan metamorphics are available the composition of a rock made up of equal proportions of these minerals has been computed and is here given.

	Rock Made Up of Equal Proportions of Pargasite and Zoisite		*Rock Made Up of Equal Proportions of Pargasite and Zoisite*
SiO_2	41.24	CaO	14.68
Al_2O_3	16.70	Na_2O	3.30
Fe_2O_3	5.49	K_2O	.51
FeO	6.87	H_2O+	4.37
MgO	6.84		
			100.00

Although this computed analysis ignores a number of minor constituents, especially titania, it is believed to give a reasonable idea of the general chemical composition of such rocks. Both from its mode of occurrence and chemical composition such a rock could result from the recrystallization of either a gabbro or

a basalt; it could represent either an endomorphic or exomorphic effect. It could have formed with the addition of a small amount of alumina, iron, lime, soda, and water.

Summary of Franciscan contact rocks.—The Franciscan metamorphics occur as small bodies on the margins of, or near, basic and ultrabasic intrusives. They are surrounded by unmetamorphosed sediments and volcanics into which they pass within short distances. When notable schistosity is present it is parallel with the original bedding. They are not the result of widespread dynamic or dynamothermal metamorphism and are not an indication of widespread alteration of the Franciscan; they are due to local pneumatolytic action.

SILICA-CARBONATE ROCK

A description of the Franciscan would not be complete without a reference to the very distinctive silica-carbonate rock which is so commonly present. Although such rocks were formed at a much later date they are the result of the alteration of serpentines and commonly are a conspicuous local feature of the Franciscan.

These interesting and highly colored and conspicuous rocks were frequently mentioned by the earlier writers, but their true nature and origin was first discovered by Knopf,[95] who definitely proved they were formed by the hydrothermal alteration of serpentine.

Although there may be considerable variation in the relative proportion of the substances present, these rocks are essentially made up of silica (opal, chalcedony, or quartz), and a carbonate which may range from an almost pure calcium carbonate to a highly ferruginous magnesian calcium carbonate. All transitions between typical silica-carbonate rocks and serpentine occur and partly or almost wholly unaltered remnants of serpentine may be present in the midst of silica-carbonate zones.

The field appearance of these rocks is very distinctive. Almost all are strongly colored in shades of yellow, yellow-brown, brownish red, or orange, due to the oxidation of the iron. Ordinarily they are made up of fine to medium crystalline ferruginous carbonate cut by a network of anastomosing veinlets or irregular areas of either clear or strongly iron-stained chalcedony; rarely they are either largely carbonate or a brown iron-stained chalcedony. Commonly the carbonate is dissolved on the surface leaving a coating of brown to red iron oxide, and a raised framework of irregular chalcedony veins. A few of these rocks have been bleached by later hydrothermal alteration. In places, they occur as small isolated areas, forming knobs, but ordinarily they occur as extremely elongate zones along faults. Naturally they are not everywhere present along faults since their formation depends on the presence of serpentine and not all serpentine is cut by the faults. However, because of the tendency for serpentine to be squeezed into shear zones, silica-carbonate rock is exceedingly common at various places along important faults.

[95] Adolph Knopf, "An Alteration of Coast Range Serpentine," *Univ. California Pub., Bull. Dept. Geol.*, Vol. 4 (1906), pp. 425–30.

In both the Santa Lucia and Diablo ranges, there are many great thrust faults between Franciscan and later rocks, and these are marked here and there by the strong development of silica-carbonate rock. Where such zones cease to mark the contact between Franciscan and later rock, and pass into the Franciscan, it is possible in many places to trace the fault by discontinuous zones of silica-carbonate rock. They are especially common along fault and shear zones because these were ready channels for the upward movement of the solutions to which they owe their origin. In the writer's opinion these solutions were derived from Tertiary and Pleistocene volcanism. Wherever there was extensive Tertiary volcanism extensive development of silica-carbonate rock is found. Thus there is a greater development in the southern Santa Lucia than in the Diablo Range, coinciding with more extensive Tertiary volcanism. The development of silica-carbonate rock by solutions essentially due to Tertiary and Pleistocene volcanism is only one phase of the alteration caused by these solutions. Where such solutions were active there may be wide hydrothermally altered zones in the Franciscan or later rocks.

Quicksilver so commonly occurs in silica-carbonate rock that it is known to prospectors as "quicksilver-rock." However, quicksilver is not confined to such rocks, but may occur in almost any type. Quicksilver occurs in hydrothermally altered Franciscan sediments and volcanics, in Knoxville, Lower Cretaceous, Upper Cretaceous, and lower Miocene sandstones and in Pleistocene volcanics in the Coast Ranges. However, quicksilver commonly occurs in silica-carbonate rock because of its porosity and common occurrence along fault zones.

It has been stated that silica-carbonate rock could be formed from basalts or even shales and sandstones. This might be possible, but of the hundreds of occurrences of these rocks observed by the writer all have originated from serpentines.

The occurrence of silica-carbonate rock along fault zones is of considerable importance to the field geologist since faults wholly within the Franciscan may be traced by this means. However, the presence of this rock does not necessarily indicate a great or important fault as it may occur along small and relatively unimportant shear zones.

THICKNESS OF FRANCISCAN

In the course of the complex diastrophic history of the Coast Ranges the Franciscan has been folded and faulted repeatedly and, as a consequence, is, in most localities, intricately folded. Furthermore, there is evidence that the earlier fold axes lie at a marked angle to the later, stronger trends. The warping of the earlier folds by stronger later folding and faulting, acting at a marked angle to the earlier, has produced very complex structures. The writer[96] has shown that these various diastrophisms were, in the Coast Ranges south of San Francisco Bay, stronger in the western than in the eastern part. In the Santa Lucia Range and

[96] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Div. Mines Bull. 118*, Pt. 2 (1941).

in the western part of the Diablo Range the Franciscan is so strongly folded and faulted that it is impossible to obtain any definite idea regarding its thickness. It is less intricately folded in the central and eastern part of the Diablo Range but, unfortunately, neither the top nor the bottom is exposed. However, in this region it is possible to measure steeply dipping, but not complexly folded, sections and to obtain a few reliable thickness figures for partial sections.

The thickest continuously exposed sections known to the writer are in the northeastern part of the Diablo Range, along Hospital and Ingraham canyons, on the north flank of the Mount Oso anticline, where there are 10,000 feet of sediments between the crest of the anticline and a fault between the Franciscan and the Cretaceous. Here the beds consist predominantly of arkosic sandstone with minor intercalations of shale and light gravels and numerous lenses of rhythmically bedded radiolarian cherts and shales. An unknown but considerable thickness of the upper part is known to be missing since at the southeast along the fault several thousand feet of volcanics and interbedded sediments appear above the sandstones and shales. Many thousand feet of sediments must be present beneath the exposed section to permit the strong folding of the region. It is believed that there must be at least 25,000 feet of sediments and volcanics in this region.

On the east, along the crest and west side of the Diablo Range, in the Mount Hamilton and San Jose quadrangles, Templeton[97] reports a thickness of 15,000–20,000 feet, but does not cite any particular section or present any definite supporting evidence.

In the northern part of the Diablo Range, in Corral Hollow in the Tesla Quadrangle, Tolman[98] states that there are 15,000 feet of sediments and that neither the top nor the bottom is exposed. He divides the Franciscan in this region into three formations, the Lower sandstones, the Corral Hollow shales and cherts, and, at the top, the Oakridge sandstone. This region has been visited several times by the writer and has been carefully mapped by Huey,[99] and both are in agreement that these three divisions are unrecognizable and unsupported by careful field work. The Franciscan is strongly folded and intruded and it is impossible to measure a section with any degree of accuracy. Huey states that the best measurements across folds he was able to obtain indicate a thickness of 12,000 feet.

In the northern part of San Benito County, west of the crest of the Diablo Range, Wilson[100] reports a thickness of 10,000 feet of sediments on the north

[97] E. C. Templeton, "General Geology of the San Jose and Mount Hamilton Quadrangles" (abstract), *Bull. Geol. Soc. America*, Vol. 24 (1913), p. 96.

[98] C. F. Tolman, Jr., chapter on "Geology of the West Coast Region of the United States," in *Nature and Science on the Pacific Coast*, p. 45. Paul Elder and Company, San Francisco (1915).

[99] A. S. Huey, "Geology of the Tesla Quadrangle," unpublished doctor's dissertation, Univ. Calif. Library, 1940.

[100] I. F. Wilson, *op. cit.* (1942).

limb of an east-west trending syncline. This thickness is based on a continuous section on Las Aguilas Creek; neither the top nor the bottom is exposed.

In the southern part of San Benito County, in the Red Mountain region, west of the crest of the Diablo Range, Mielenz[101] states that, in a syncline, there are 9,000 feet of Franciscan rocks, including 12 sills of serpentine and fully 4,000 feet of pillow basalts and greenstones. This is a comparatively small area of Franciscan that is isolated by faults and Tertiary overlaps.

In the San Luis folio Fairbanks reports 10,000 feet of sandstones along the coast northwest of Port Harford. Because of the strong folding and faulting of the region this figure is, at best, a rough estimate.

The Mesozoic rocks of the northern Coast Ranges have been folded and faulted to the same extent as those south of San Francisco Bay, and furthermore the exposures in general are much poorer because of the deep soil and heavy mantle of vegetation. Hoots[102] has described a thick section of rocks in Humboldt County which he believed to be the equivalent of Franciscan, Knoxville, Horsetown and Chico. However, on the east in Humboldt County and on the south in Mendocino County, this entire series is unconformably overlain by sediments of Lower Cretaceous age, and they are regarded by the writer as the equivalent of the Franciscan, or the Franciscan and Knoxville combined. These beds consist of 8,000 feet (thickness according to Hoots but believed to be only very approximate) of dark gray sandstones, black shales, and limestones, overlain by sandstone, shale, basalt, radiolarian chert, and red and gray foraminiferal limestone of unknown thickness.*

In southern Tehama and northern Mendocino counties there is a great thickness of arkosic sandstones, shales, cherts, basalts, and intrusive sills. The writer has crossed this rugged region several times, but has been unable to obtain any reliable estimate of the thickness except that it appears to be in excess of 15,000 feet. Similar thicknesses are exposed east of Clear Lake.

It is impossible at present to give any definite figures either for the thickness of the Franciscan or for variations in thickness from place to place. However, there are excellent and continuous sections at least 10,000 feet thick, in which neither the bottom nor the top is exposed, and where there are known to be several thousand feet of stratigraphically higher beds cut out by faulting. These beds form the limbs of strong folds; it is unlikely that folding of the type encountered could have taken place unless the exposed beds were underlain by at least 10,000 feet of bedded sediments and volcanics. The writer does not believe that an es-

[101] R. C. Mielenz, *op. cit.* (1936).

[102] H. W. Hoots, "Oil and Gas Exploration in Southwestern Humboldt County, California," *U. S. Geol. Survey Memorandum for the Press* (March 5, 1928).

* It should be noted that not all of the area of "Mesozoic rocks" shown on the map accompanying Hoots' report is Franciscan. Soft, dark gray Cretaceous shales occur beneath the Miocene and Pliocene beds and above the Franciscan in the Bear River syncline. These are well exposed along the coast north of the mouth of Bear River. Similar shale underlies the Miocene in the vicinity of Briceland.

timate of 25,000 feet for the thickness of the Franciscan is excessive. Naturally, it is not everywhere so thick; undoubtedly, like the Cretaceous, it thins and thickens from place to place.

BASEMENT ON WHICH FRANCISCAN WAS DEPOSITED

Although the base of the Franciscan never has been discovered in the California Coast Ranges there is indirect evidence indicating the nature of the basement on which the Franciscan was deposited.

In the Coast Ranges south of San Francisco Bay there is no evidence of any rocks intermediate in age between the Franciscan and the crystalline complex (Sur series, Gabilan marble, and Santa Lucia granodiorite). This region has been intricately folded and faulted and deeply eroded and if such rocks existed they should be exposed somewhere in the Santa Lucia Mountains. If any rocks were deposited in this region after the deformation of the Sur series and the intrusion of the Santa Lucia granodiorite, they were removed prior to the deposition of the Franciscan. The writer can see no evidence to indicate that this region, the Santa Cruz Mountains and the Santa Lucia Range, was submerged between the time of deformation of the crystalline complex and the deposition of the Franciscan.

The Amador and Mariposa sediments and volcanics (Middle and lower Upper Jurassic) accumulated in a basin east of the present Coast Ranges, in what is now the Great Valley and the Sierra Nevada, but there is no evidence to indicate that this basin extended as far west as the Santa Lucia Range. The presence of débris of the Coast Range crystalline complex in these sediments and their tendency to become coarser westward indicate the presence of a land mass in the Coast Ranges, or at least in the western part of the Coast Ranges, during the Middle and lower Upper Jurassic.

There is abundant débris of the Sur series and Santa Lucia granodiorite in the Franciscan and there are no known rocks intermediate in age between the two in the western part of the central Coast Ranges. Hence there seems to be little doubt that the Franciscan rests on the Sur series, Gabilan marble, and Santa Lucia granodiorite in the western part of the Coast Ranges south of San Francisco Bay. There is no evidence regarding the basement in the Diablo Range or the western margin in the San Joaquin Valley; it may be in part Coast Range crystalline complex and in part Sierran basement.

In the northern Coast Ranges the débris in the Franciscan indicates that it was deposited, in part at least, on granodiorite and the Salmon and Abrams schists. In the eastern part of the northern Coast Ranges the presence of Mariposa slates and schists in close proximity to unmetamorphosed Franciscan indicates that the basement included beds as late as the Mariposa.

In the extreme northern part of California and in southwestern Oregon, the Franciscan rests on and overlaps Dothan and Galice slates (equivalent to Amador and Mariposa in California). In northern California and southern Oregon the

basement of the eastern margin of the Franciscan geosyncline appears to have been Paleozoic and Jurassic volcanics and sediments, but westward along the Oregon coast the basement appears to have been ancient crystalline schists, probably equivalent to the Salmon and Abrams schists.

SOURCE OF FRANCISCAN DETRITUS

The two strongest lines of evidence suggesting the source of the bulk of the clastic material making up the Franciscan sediments are: (1) the nature of the material, and (2) the direction toward which the sediments become coarse. The type of material already has been described. The arkosic material making up the sandstones might have come either from rocks similar to the Coast Range crystalline complex or from the granodiorites of the Sierra Nevada, if these had been exposed at the time, which is doubtful. However, when the nature of the coarser detritus is considered, the evidence is more conclusive. The writer is familiar with all of the rock types now exposed in the bedrock complex of the Sierra Nevada and can see no resemblance between these and the pebbles and boulders in the Franciscan. The predominant types in the Franciscan conglomerate definitely are not Sierran; there is no indication they were derived from the east. The evidence afforded by type of material favors a western, rather than an eastern source.

In the northern Coast Ranges, between Lat. 39° and 40° N., there is a general coarsening of grain in the Franciscan sediments toward the west; on the east, shales form a greater proportion than on the west. While it is true that it is impossible positively to state that we are dealing with equivalent horizons from the Pacific Ocean to the Sacramento Valley, this general westward coarsening is regarded as significant. A definite example of the westward coarsening of equivalent horizons in a distance of 15 miles across the strike occurs between the western edge of Berryessa Valley and Napa Valley. Here, in the same general horizon in the upper part of the Franciscan, sandstones greatly predominate over shales on the west and shales equal or exceed sandstones toward the east.

In the southern Santa Lucia Range the rocks also appear to become coarser westward; conglomerates are more abundant and coarser on the west than on the east.

This westward change, the absence of pebbles and boulders that may be ascribed to an eastern source, and an apparent thinning toward the east indicate that the detritus making up the Franciscan clastics was largely derived from a land mass west of the present coast line. The rather uniform character of the detritus, its nature, and the great areal extent of the Franciscan indicate that this land mass was large, probably at least as long as much of the present California and Oregon coasts, and of notable relief. It is believed that this land mass, which was strongly uplifted and rejuvenated at the time of, or immediately after, the Nevadan orogeny, contributed a large part of the detritus making up both the Franciscan and the Knoxville. At the beginning this land mass was high and

rugged, with streams of high gradient, and supplied chiefly coarse mechanical detritus. As the land mass was worn down the nature of the material gradually became finer, resulting in finer-grained clastics in the upper part of the Franciscan and in the Knoxville.

Although it appears that the bulk of the detritus making up the clastic sediments of the Franciscan and Knoxville came from a western source, the possibility of an eastern source for a part of the detritus can not be ignored. The latest pre-Franciscan sediments deposited in the Sierra Nevada region, the Mariposa sandstones and slates, are lithologically similar to the Franciscan, the sandstones being arkosic and the shales of the same general character as those in the Franciscan. Although these beds were strongly deformed and rendered slaty prior to the deposition of the Franciscan, the surface beds could not have been so deformed. It is possible that the erosion of the unmetamorphosed surface beds of the Sierran region contributed a considerable amount of débris to the geosyncline to the west in which the Franciscan accumulated.

GENERAL STATE OF ALTERATION OF FRANCISCAN

Several things have contributed to an all too general belief in the advanced stage of alteration of the Franciscan. In the first place, the early writings of Whitney and Becker, and their statements that the Franciscan was strongly metamorphosed Cretaceous has been of considerable influence. In the second place, a misinterpretation of the contact schists has led many to consider the Franciscan in general to be strongly metamorphosed. In the third place, the general disordered appearance of many Franciscan outcrops gives a false impression of alteration.

Leaving the contact schists, which have been shown to be caused by local pneumatolytic action, out of consideration, the Franciscan in general is not greatly altered and in some places is practically unchanged. However, the degree of alteration varies from place to place, which is not surprising considering the depth of burial and its variation and the various periods of diastrophism through which the Franciscan has passed.

Many of the shales interbedded with the sandstones are slaty, but this is to be expected considering the depth to which the Franciscan has been buried beneath Cretaceous and Tertiary sediments. In a number of places it is clear that the Franciscan has been buried beneath at least 25,000 feet of Upper Cretaceous alone and a great but less definitely known thickness of Lower Cretaceous and Tertiary. There is little doubt that the Franciscan, in many regions, was covered by at least 20,000–40,000 feet of later sediments. This great load caused the development of a weak slaty cleavage in the shales. This is well shown along the west side of the Great Valley of California.

Throughout the Coast Ranges the Franciscan was folded and faulted at least twice in the Cretaceous, several times during the Eocene and Miocene, and severely in both the Pliocene and Pleistocene. As a rule the late severe folding

took place under a comparatively thin cover and no notable dynamic metamorphism resulted. These diastrophisms have locally deformed and strongly compressed and sheared the Franciscan (and the Knoxville as well in some places) and have caused the local development of slaty cleavage and zones of strong mylonitization in which the Franciscan, as well as later beds, have been sheared, crushed, and granulated. The Franciscan is in many places surprisingly little deformed only a short distance away from such zones.

During the deposition of the Franciscan there were frequent outpourings of contemporaneous volcanics, sometimes reaching great thicknesses locally. During and after deposition the Franciscan was extensively intruded, in many regions, by plugs, dikes, and great irregular sill-like and laccolithic bodies of basic and ultrabasic rocks. Furthermore lenses of brittle chert are of frequent occurrence in the midst of sediments and volcanics. All of these diverse, but perfectly natural processes, contributed to the heterogeneity of the Franciscan in general. During the various diastrophisms suffered by the Franciscan these heterogeneous elements yielded in various ways. The sediments were crushed against the more resistant igneous bodies and, locally, were greatly sheared and distorted. The more brittle cherts were greatly plicated and fractured since they yielded in a different manner than the more plastic sediments. This difference in yielding and the crushing of the sediments against more rigid igneous bodies is in large part responsible for the usual misconception regarding the metamorphism of the Franciscan. Where intrusive bodies are scarce or lacking, resulting in greater homogeneity, the Franciscan does not give the same impression of advanced alteration. This is particularly true of certain parts of the eastern side of the Diablo Range.

Another cause for the locally disordered appearance of the Franciscan lies in the late history of the Coast Ranges. The late Pliocene and mid-Pleistocene orogenies folded, thrust faulted and uplifted the various ranges of the Coast Range system. In many places the Franciscan forms the squeezed core of these ranges having been elevated by folding and thrust over later softer sediments. This has resulted in great slides along the oversteepened fronts, especially where shales and serpentines are present, and has caused the Franciscan to appear as disordered masses and large slide breccias of heterogeneous blocks, in places greatly sheared and slickensided. These slides and the squeezed cores of the ranges give an erroneous impression of heterogeneity and complexity. All of these factors have combined to give an impression of metamorphism and complexity that is more apparent than real.

Where intrusions or great lenses of contemporaneous volcanics against which the sediments might be crushed are scarce or absent and where slides are not numerous, the Franciscan is surprisingly regular in its attitudes and little difficulty is encountered in working out the nature and trend of the folds.

The maximum alteration of the Franciscan over a fairly wide area is found in the northern Coast Ranges in Tehama and Trinity counties where slaty and

even schistose rocks are numerous. However, even in this region, schistose and strongly veined rocks grade within short distances laterally into little altered sediments. The rocks, both sediments and volcanics, are cut by innumerable small veins of quartz; the degree of veination roughly corresponds with the amount of recrystallization. Highly veined and moderately schistose rocks grade along the strike into unveined slightly slaty sediments. Little altered sediments commonly appear in the midst of strongly recrystallized rocks. The metamorphism appears to be due chiefly to depth of burial beneath an exceptionally thick Cretaceous section and to hydrothermal action brought about by an exceptionally large number of intrusions. The great depth of burial may have increased the temperature to such an extent that a small additional increase, caused either by igneous intrusion or even slight diastrophism, was sufficient to bring about local recrystallization. It has been stated that the rocks in this region are much older than the Franciscan, but this is hardly likely for two very good reasons. In the first place, the rocks contain all the usual lithologic types characteristic of the Franciscan and grade outward into unaltered Franciscan. In the second place, they contain *Aucella* similar to those in the Franciscan and Knoxville; these *Aucella* are not radially striated as are those in the Mariposa. Fossils have been found in some of the less veined and recrystallized areas on the Paskenta-Covelo road east of Anthony Peak and on the Forest Service road about 2 miles north of Black Diamond lookout station.

The Franciscan as a whole is little metamorphosed; the maximum alteration, aside from the pneumatolytic contact schists, has been accomplished by depth of burial and hydrothermal action and is local, not general. It has not been metamorphosed to the same extent or as sharply folded as the Mariposa slates of the Sierra Nevada or the Galice of Oregon.

AGE OF FRANCISCAN

The various statements regarding the age of the Franciscan and its possible correlatives have been reviewed. The evidence afforded by fossils, the conclusions drawn from them, and the stratigraphic evidence are here discussed.

Fossils, other than radiolaria and foraminifera in the cherts and limestones, are so scarce and so poorly preserved, as a rule, as to be of little value. Even the abundant radiolaria and foraminifera are so recrystallized as to render specific determination difficult if not impossible. Determinations of age based on these microscopic forms have been exceedingly inconsistent, ranging from Carboniferous to Upper Cretaceous for material from the same locality. Thus far determinations of age by means of radiolaria and foraminifera have been of no value.

The great scarcity of fossils possibly arises from two causes. Apparently the conditions of deposition, shallow muddy water and rapid deposition, were not particularly favorable for an abundance of organic life. These conditions were not peculiar to the Franciscan as there are considerable thicknesses of Cretaceous sandstones and sandy shales in which fossils are very scarce. Furthermore, the

subsequent history of the Franciscan has not been favorable for the preservation of organic remains. Not only have the sediments in many places been crushed against the more massive intrusives, but also groundwaters at various periods have had ready access to the steeply tilted and highly jointed beds and have had abundant opportunity to dissolve and destroy calcareous shells. The writer has found poorly preserved casts in the clastic sediments in several places in the Santa Lucia and Diablo ranges, but the preservation has been too poor for their determination. However, they are as well preserved as the casts supposed to have come from Alcatraz Island, described by Gabb,[103] Stewart,[104] and Anderson.[105] Stewart states that *Inoceramus elliotii* Gabb is "probably Cretaceous" and Anderson that *Lucina alcatrazis* is "probably Paskenta" (Lower Cretaceous). These determinations are based on very poorly preserved and fractured casts, as may be seen by consulting the figures in the publications cited. The preservation is not believed to be sufficient to justify a precise age determination, especially since there are no similar species with which they may be compared.

Aside from the stratigraphic position of the Franciscan below the Cretaceous the assignment to the Jurassic has rested chiefly on fossils from the Slate's Springs region, in the northern part of the Santa Lucia Range, described by C. H. Davis,[106] who considered them to be Jurassic, a conclusion subscribed to by Crickmay,[107] in 1931. The fossils occur in steeply dipping, faulted and sheared shales[108] exposed along the precipitous coast in Monterey County. This locality was originally discovered by Fairbanks and a brief description of the fossils given by Stanton,[109] who stated:

> The *Inoceramus* seems to me to be the most important form in determining the age, as it is confined to the Mesozoic, and a species of this size and type is probably not older than the Jurassic and might be Cretaceous.

However, Stanton, probably influenced by Fairbanks' descriptions of the field and stratigraphic relations,[110] assigned the beds to the Jurassic. These statements undoubtedly influenced the assignment of the fossils to the Jurassic by Davis

[103] W. M. Gabb, *Paleontology of California* (1869), pp. 193, 246.

[104] Ralph B. Stewart, "Gabb's California Cretaceous and Tertiary Type Lamellibranchs," *Philadelphia Acad. Nat. Sci. Spec. Pub. 3* (1930), p. 106.

[105] F. M. Anderson, "Lower Cretaceous Deposits of California and Oregon," *Bull. Geol. Soc. America Spec. Paper 16* (1938), p. 121.

[106] C. H. Davis, "New Species from the Santa Lucia Mountains, California, with a Discussion of the Jurassic Age of the Slates at Slate Springs," *Jour. Geol.*, Vol. 21 (1913), pp. 453–58.

[107] C. H. Crickmay, "Jurassic History of North America; Its Bearing on the Development of Continental Structure," *Proc. Amer. Philos. Soc.*, Vol. 7 (1931), p. 53.

[108] The name Slate's Springs or "Slate Springs" is not based on the lithologic character of the rocks, but on the name of a pioneer in the region, Thomas B. Slate, who settled there in 1868. See G. A. Waring, "Springs of California," *U. S. Geol. Survey Water-Supply Paper 338* (1915), pp. 56–57.

[109] T. W. Stanton, in H. W. Fairbanks, "The Stratigraphy of the California Coast Ranges," *Jour. Geol.*, Vol. 3 (1895), pp. 415–33.

[110] H. W. Fairbanks, "Review of Our Knowledge of the California Coast Ranges," *Bull. Geol. Soc. America*, Vol. 6 (1895), p. 82; "Stratigraphy at Slate's Springs, with Some Further Notes on the Relation of the Golden Gate Series to the Knoxville," *Amer. Geol.*, Vol. 18 (1896), pp. 350–56.

and Crickmay. However, even from the first discovery of these fossils, there was no general agreement regarding their age. Merriam[111] stated that the fauna was of Cretaceous, rather than Jurassic aspect.

The Lucia Quadrangle, in which the locality occurs, has been mapped by Reiche,[112] who has shown that the beds at Slate's Springs do not underlie the Franciscan, as was the earlier belief, but that the Franciscan is thrust westward over them. New fossils were collected and the older collections were re-examined by Nomland and Schenck,[113] who proved conclusively that the beds are Upper Cretaceous and not Jurassic.

The Cretaceous beds at Slate's Springs are not only Upper Cretaceous but are upper Upper Cretaceous, probably post-Turonian. They are to be correlated with the Asuncion group,[114] the most widespread of all of the Cretaceous units in the Santa Lucia Range. These upper Upper Cretaceous sediments rest on lower Upper Cretaceous (Cenomanian and Turonian) sediments with marked unconformity and overlap across lower Upper Cretaceous, Lower Cretaceous and Franciscan onto the crystalline complex (Santa Lucia granodiorite and Sur series).

All of the reported Franciscan fossil localities have been visited by the writer; practically all of these are in younger sediments which have been confused with the Franciscan. Probably the most frequently mentioned locality, after Slate's Springs, is the one described by Fairbanks,[115] in the San Luis Quadrangle, 6 miles north of Port Harford. Regarding the fossils from this locality, T. W. Stanton states:

> The collection consists of a number of distorted specimens of a single species of *Pecten*, which is of a type that might be either Jurassic, Cretaceous, or Tertiary. It should be compared with *Pecten pedroanus* (Trask), a Miocene species originally described as a *Plagiostoma* and assigned to the Cretaceous. The strange and interesting thing about this formation (Franciscan) is that none of the molluscan remains yet found in it are referable to forms that have been described from the Pacific Coast, while they are practically indeterminate as far as settling the age of the formation is concerned.

The fossils actually are from Miocene beds; the enclosing diabase "dikes" described by Fairbanks are not Franciscan, but the typical analcite diabase sills so commonly present in the Miocene. The lithologic character is also that of the Miocene and the same beds farther north rest unconformably on both the Franciscan and Upper Cretaceous.

[111] J. C. Merriam, letter to L. F. Ward in *U. S. Geol. Survey 20th Ann. Rept.*, Pt. 2 (1898–99), p. 338.

[112] P. Reiche, "Geology of the Lucia Quadrangle, California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 24 (1937).

[113] J. O. Nomland and H. G. Schenck, "Cretaceous Beds at Slate's Hot Springs, California," *ibid.*, Vol. 21 (1932), pp. 37–49.

[114] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Min. Bur. Bull. 118*, Pt. 2 (1941).

[115] H. W. Fairbanks, "San Luis, California," *U. S. Geol. Survey Geol. Atlas Folio 101* (1903), p. 2.

Another fossil locality in the Franciscan was described by Diller[116] from a limestone about 2 miles north of Laytonville, Mendocino County. Diller states as follows.

> Imperfect fossils were found in the limestone near Laytonville. Among them Dr. Girty reports a large but indeterminable gastropod, and a number of small organic bodies which appear to belong to the genus *Mitcheldeania*. This genus has not heretofore been recognized in this country, but the name was given to similar obscure organisms from the Carboniferous rocks of Great Britain. As the form in hand is so similar to the British species (*M. gregaria*) as to be probably identical with it, it seems more than likely that the California rocks are of the same general age.

The writer visited this locality and collected a large amount of material which was sectioned and studied under the microscope. The limestone varies from white to deep red in color and, on its southern end, is interbedded with red radiolarian cherts and red shales. Limestones and cherts are inclosed in typical Franciscan sandstones and volcanics. The foraminifera, the "small organic bodies" of Girty, are identical with those in many other Franciscan limestones. The radiolaria, which are abundant in the red limestones, cherts, and shales, are of the same types found in the typical Franciscan cherts. Since these foraminifera also have been regarded as Upper Cretaceous the writer does not consider that their assignment to the Carboniferous should be taken seriously, especially when their preservation is considered.

W. D. Smith[117] compared the radiolaria in Franciscan cherts in Oregon with those in similar rocks in the Philippines and the Netherlands East Indies, known to be of Triassic and Jurassic age. As has been mentioned previously, Hinde stated that the radiolaria in the California cherts were similar to those in the Jurassic and Cretaceous of Europe. Both Smith's and Hinde's suggested correlations are obviously based on lithologic similarity, rather than faunal identity.

The fossils thus far reported from the Franciscan actually have come from Upper Cretaceous and Miocene beds, with the exception of the poorly preserved casts from Alcatraz Island and the radiolaria and foraminifera.

The writer collected a large number of well preserved fossils from beds having a typical Franciscan lithologic character in the Nipomo Quadrangle, San Luis Obispo County. Although these are from typical Franciscan beds they are stated to be late Upper Jurassic, and similar to forms from the Knoxville of northern California. These beds and the fossils are discussed with the Knoxville.

In 1936, Neil Smith, a graduate student in the University of California, while engaged in field work in the Carbona Quadrangle under the writer's direction, found a boulder of red radiolarian chert containing what later was found to be an ichthyosaur snout. This worn boulder came from an upper San Pablo (upper

[116] J. S. Diller, "Topographic Development of the Klamath Mountains," *U. S. Geol. Survey Bull. 196* (1902), pp. 65, 66.

[117] W. D. Smith, "Notes on the Radiolarian Cherts in Oregon," *Amer. Jour. Sci.*, 4th Ser., Vol. 42 (1916), pp. 299–300.

Miocene or lower Pliocene) conglomerate about one mile south of Corral Hollow Creek in the Carbona Quadrangle. Several years later a similar boulder was found in recent stream gravels in El Puerto Creek, west of Patterson. Both localities are on the east flank of the Diablo Range, which in this region is largely made up of the typical Franciscan assemblage including numerous lenses of radiolarian cherts. Débris of chert, as well as all other Franciscan types, is abundant in later formations, especially in the Cretaceous, Pliocene, Pleistocene, and recent stream gravels. Sections were made of both boulders and compared with many sections of the radiolarian cherts occurring in place on the west; they are identical and there can be no question as to the source of the boulders. Careful search has been made at the outcrops of the cherts, but thus far no additional remains have been found.

Both boulders were sectioned and carefully studied by C. L. Camp, who concluded that they were practically identical with Tithonian ichthyosaurs of Europe, and with certain supposed Lower Cretaceous forms from Australia.[118] The following is the abstract of Camp's paper, presented before the 1941 meeting of the Cordilleran section of the Geological Society of America.

> Two ichthyosaur rostra enclosed in worn chert cobbles have been discovered in gravels on the west side of the San Joaquin Valley. The character of the chert and the associated radiolaria definitely indicate derivation from the adjacent Franciscan chert beds. Characters of the teeth and the shape and relations of the bones and canals in the snout seem to show a close relationship to ichthyosaurs from the Upper Jurassic of Europe, particularly *I. posthumus* from the Solnhofen beds of Tithonian (lower Portlandian) age. *I. australis* from the Lower Cretaceous of Queensland also appears to be related. Some of the ichthyosaurs from the Upper Jurassic are very similar to forms in the Lower Cretaceous. The Triassic and Lower Jurassic ichthyosaurs are most certainly not comparable with the two Franciscan species at hand.

The "Lower Cretaceous" age of the Australian beds containing similar ichthyosaurs has not been firmly established. That the Franciscan is older than the Lower Cretaceous is shown by the well established fact that, in the region in which the ichthyosaurs are found as well as in other parts of the Coast Ranges, the Franciscan is unconformably overlain by beds containing a very early Lower Cretaceous fauna.

As a result of many years of field work in the Coast Ranges of California and Oregon, and studies in the Sierra Nevada, the writer, in 1937, reached two unorthodox conclusions regarding the Franciscan and Knoxville. First, that the Franciscan is not an assemblage of beds of uncertain age and no particular stratigraphic value, but a unit whose age may be determined rather precisely and, second, that there is no unconformity between the Franciscan and Knoxville.[119]

Instead of extending over a considerable part of the geologic column the Fran-

[118] Charles L. Camp, "Ichthyosaurs from the Franciscan Group of Central California," *Jour. Paleon.* (1942). (In press.)

[119] N. L. Taliaferro, "Upper Jurassic-Lower Cretaceous Unconformity in California" (abstract), *Proc. Geol. Soc. America* (1937), p. 254; also unpublished paper given before the Pacific Science Congress, Berkeley meeting, 1939.

ciscan is confined to rather narrow limits, being younger than the Kimmeridgian and older than the lowermost Lower Cretaceous; thus, it is Tithonian, in the sense as defined by Muller.[120]

The evidence on which this is based has been presented previously,[121] and is only briefly outlined here. Nowhere in California does the Franciscan come into direct contact with the Mariposa slates of the Sierra Nevada although unmetamorphosed Franciscan is in close proximity to equivalent slates in northern California. However, in southwestern Oregon the Franciscan, having the same lithologic character and depositional sequence previously described, rests unconformably on and overlaps the Galice slate which, on both lithologic and faunal grounds, is the correlative of the Mariposa of California. The age of the Mariposa and Galice is known to be Upper Jurassic, Oxfordian and lower Kimmeridgian; hence, the Franciscan is younger than the lower Kimmeridgian. In northern California the last phase of the late Upper Jurassic depositional cycle, the Knoxville (restricted or "lower Knoxville") contains Tithonian fossils. Both Franciscan and Knoxville are, throughout the Coast Ranges, unconformably overlain by the Paskenta stage of the Lower Cretaceous, which contains a very early Lower Cretaceous fauna. Both the Franciscan and the Knoxville were deposited in the late Upper Jurassic, after the Nevadan orogeny,[122] since the Mariposa and Galice were strongly deformed, dynamically metamorphosed, and eroded before the deposition of the Franciscan. Since these events must have required an appreciable time and since the youngest deformed, pre-Franciscan beds are lower Kimmeridgian it is believed that the Franciscan is confined to the Tithonian although the possibility exists that deposition began in the uppermost Kimmeridgian.

Both the stratigraphic evidence and fossil evidence (the ichthyosaurs described by Camp and the fossils collected by the writer) agree and clearly indicate that the Franciscan may be accurately dated.

Knoxville

As used here the term Knoxville includes the "lower Knoxville" of earlier writers, that is, that part of the original Knoxville that is known to be Jurassic and which is unconformably overlain by the "upper Knoxville" (Paskenta stage of the Lower Cretaceous). The evidence for the Jurassic age of the restricted Knoxville and the literature on the subject have been discussed previously.

[120] S. W. Muller, "Standard of the Jurassic," *Bull. Geol. Soc. America*, Vol. 52 (1941), pp. 1427–44.

[121] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Min. Bur. Bull. 118*, Pt. 2 (1941).
———, "Geologic History and Correlation of the Jurassic of Southwestern Oregon and California," *Bull. Geol. Soc. America* (1942). (In press.)

[122] The writer has shown that the Nevadan revolution was a two-phase event compounded of an orogeny of the first magnitude, followed by a period of widespread batholithic invasion. The orogenic episode can be dated precisely, but the batholithic phase is less susceptible to exact dating. *Geol. Soc. America*, 1942. (In press.)

DISTRIBUTION

The distribution of the Knoxville is essentially the same as that of the Franciscan, but the actual areal extent is much less because of removal by erosion. It occupies a long belt on the west side of the Sacramento Valley almost from San Francisco Bay to Tehama County, where it and the Franciscan are gradually overlapped by the Lower Cretaceous. It is also exposed in areas in the northern Coast Ranges, in most places where it has been preserved by downfolding. A part of the area in northern California shown as Franciscan on the state geological map is Knoxville, in the sense in which the term is used at present. Although it covers a comparatively small area in the Coast Ranges between San Francisco Bay and Santa Barbara County, it is widely distributed, generally occurring in comparatively small infolded or downfaulted areas. In places, it is in the core of anticlines from which the Cretaceous and Tertiary cover has been stripped, for example, east of Priest Valley and Waltham Canyon. Its wide distribution from Oregon to Santa Barbara County, and from the Great Valley of California to the Pacific Ocean, and its similar lithologic character wherever found, indicate that it was deposited in a geosyncline of considerable extent, the same basin as that in which the Franciscan accumulated.

LITHOLOGY

The best known and most frequently studied section of the Knoxville is along the west side of the Sacramento Valley and most of the literature on the Knoxville is based on observations in this area. As usually described, the Knoxville is stated to consist of a great thickness (up to 14,000 feet) of dark clay shales, with subordinate sandstones and conglomerates. This description is adequate as far as it goes, but it omits a number of important rocks in the Knoxville. The chief reason for most of the incomplete descriptions is due to the refusal of most of the earlier workers to consider as Knoxville any igneous rocks or chemical sediments such as cherts; where such rocks were found they were regarded as Franciscan, notwithstanding the structural and stratigraphic complexities introduced by this procedure.

It is true that the great bulk of the Knoxville in the readily accessible belt along the west side of the Sacramento Valley is made up of dark clay shale, sandstone, and pebble conglomerates. However, even here other rocks are present, especially in the lower part. Along the west side of the Sacramento Valley much of the lower part of the Knoxville is obliterated by the intrusion of thick sills of serpentine some of which rise to the top of the Upper Jurassic sediments. The great sill in the lower part decreases in thickness westward and, where the Knoxville is present in infolded synclines, separated from the valley margin by anticlines, the entire lower part, with its diverse rock types, may be observed. Only in such areas is the lower part of the Knoxville exposed.

Typical of such regions is that about 4 miles north of Wilbur Springs in Colusa

County. Here the typical Franciscan assemblage of sandstones, dark clay shales, cherts, basalts, and agglomerates is present. Flows of basalt, with interbedded red radiolarian cherts, pass upward into basalt agglomerates with which are interbedded black clay shales and thin sandstones which contain Knoxville fossils *Belemnites* and *Aucella*. There is a steady upward decrease in volcanic agglomerates and an increase in the proportion of dark clay shales until finally the shales greatly predominate. Thin local flows of pillow basalt, identical with those in the Franciscan below occur in the shales; typical Knoxville fossils are found in the shales and sandstones both above and below the pillow basalts. There is no definite contact here between the Franciscan and the Knoxville. Similar relations may be observed along the west side of Berryessa Valley and in Pope Valley. In the latter area there are impure cherts, basalts, and basalt tuffs and agglomerates interbedded with fossiliferous dark Knoxville shales and thin sandstones. Nowhere has the writer seen an unconformity at the base of the Knoxville, in the sense in which the term is used at present. The lower part of the Knoxville, containing fossils, is similar lithologically to the upper part of the Franciscan. This is strikingly illustrated in the Nipomo and Branch Mountain quadrangles, in southern San Luis Obispo County, not far north of the Cuyama River, which here forms the boundary between San Luis Obispo and Santa Barbara counties. Exposed along the river and on the flanks of the high rugged ridges on the north is typical Franciscan—sediments, volcanics, intrusives, and schists. Above these is a long belt of dark clay shales and sandstones, intruded by serpentine and diabase, here and there with the development of glaucophane schists; flows of basalt and cherts are sparingly present in the shales. Not only are these beds lithologically identical with the Knoxville, but they contain an abundant Knoxville fauna, *Aucella*, *Ammonites*, and *Belemnites*. These shales and sandstones pass upward into a thick series of vesicular basalt flows, in places with well developed pillow structure, with which are interbedded dark shales and sandstones also containing Knoxville fossils. These basalts, fully 2,000 feet thick, are overlain by more than 600 feet of rhythmically bedded red radiolarian cherts and shales which in turn pass upward into typical sparingly fossiliferous Knoxville shales and sandstones. These are unconformably overlain by a conglomerate containing abundant pebbles, boulders, and angular blocks of all the underlying beds. This conglomerate contains an early Lower Cretaceous fauna, chiefly *Belemnites* and *Aucella*.

Over a period of years the writer has collected many fossils from the dark shales below the pillow basalts and cherts, from shales interbedded with the basalts and from the shales above the cherts and below the Lower Cretaceous conglomerate. This fauna has not been completely studied as yet, but sufficient work has been done to establish the Tithonian age of the beds. The following forms have been described by Crickmay.[123]

[123] C. H. Crickmay, "A New Jurassic Ammonite from the Coast Ranges of California," *Amer. Midland Naturalist*, Vol. 13 (1932), pp. 1–11.

Protothurmannia rezanoffiana Crickmay
Beriasella cf. *calisto* d'Orbigny
Substeueroceras sp.
Crioceras sp.
Bochianites sp.
Phylloceras sp.
Lytoceras sp.
Pachyteuthis ? sp.
Aucella terebratuloides Lahusen

All of these fossils came from Sec. 32, T. 12 N., R. 32 W., and Sec. 5, T. 11 N., R. 32 W., S.B.B. and M., in the Nipomo Quadrangle, southwest of Stanley Mountain, between Alamos Creek and Cuyama River. Similar forms occur in the shales below and interbedded with basalts on the northwest and for a distance of 5 miles east, in the Branch Mountain Quadrangle. Crickmay's statement that the beds containing these fossils are unconformably beneath beds containing *Aucella piochii* is utterly without foundation as *A. piochii* is the most abundant fossil associated with the forms listed.

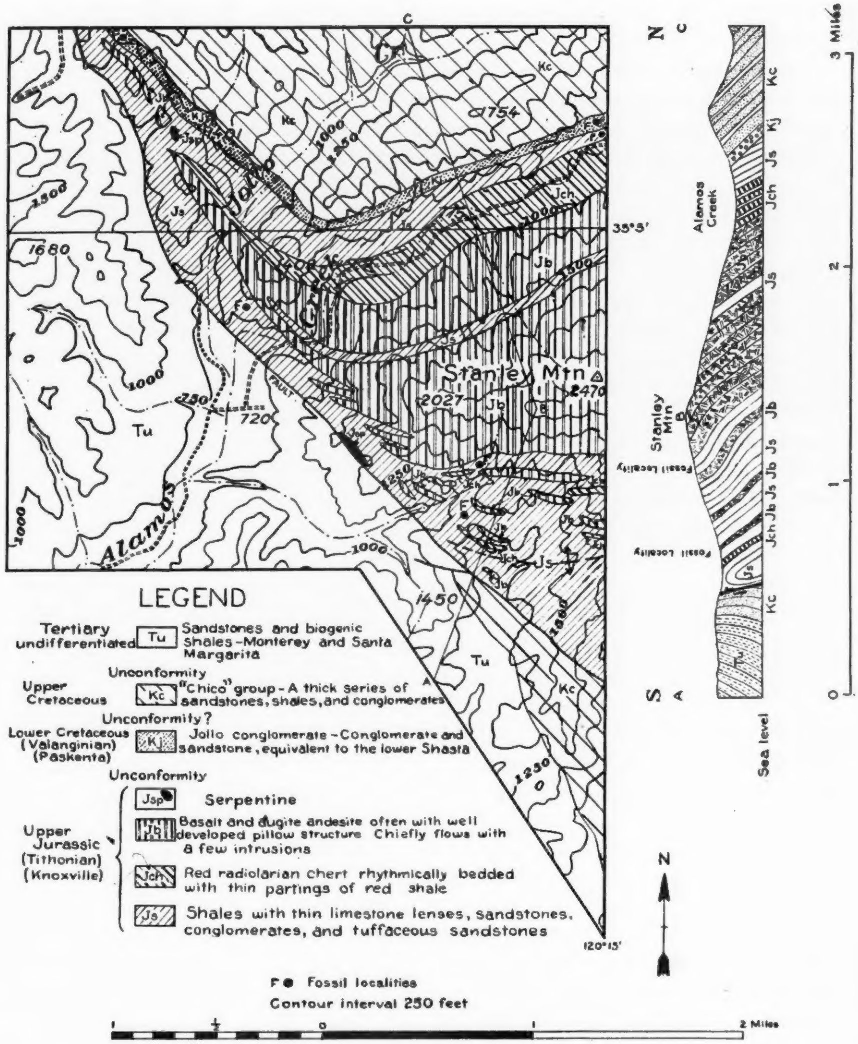
F. M. Anderson determined the following from the Lower Cretaceous conglomerate unconformably overlying the Franciscan-Knoxville beds. These came from a 3-mile stretch in Secs. 28, 29, and 30, T. 12 N., R. 32 W.

Aucella lahuseni Pavlow
Aucella nuciformis Pavlow
Acroteuthis onoensis Anderson
Turbo paskentaensis Stanton

Anderson states (letter dated April 3, 1936) that all these forms occur in the basal beds of the Shasta series (Paskenta) in Tehama County, and are Lower Cretaceous in age, "near the base of the series." Figure 7 is a geologic map of a part of the Nipomo Quadrangle showing the relations just described.

In this region, in the Nipomo and Branch Mountain quadrangles north of the Cuyama River, there is a clear and unmistakable example of beds with typical Franciscan lithologic character but which contain fossils supposed to be characteristic of the Knoxville as exposed along the west side of the Sacramento Valley. Evidently in the Cuyama River region, in San Luis Obispo County, volcanism, with the attendant development of siliceous sediments (radiolarian cherts and shales) continued almost to the close of the Jurassic. Typical Knoxville shales were accumulating in some regions while in others the deposition of the normal type of "Knoxville" sediments was interrupted by submarine flows of basalt and the formation of cherts. This is not peculiar to the San Luis Obispo County region as thin flows of pillow basalts and thin lenses of red radiolarian cherts occur in the Knoxville at the type section, west of the Redington Quicksilver Mine in Napa County. Impure cherts also occur in Knoxville shales in Pope Valley in Lake County.

As a matter of record, the writer lists the localities in which he has found basalts, many having a pillow structure, in shales containing what is usually regarded as a typical Knoxville fauna. 1. On Olds Creek in the extreme northern part of the San Luis Quadrangle. Excellent Knoxville fossils were found below the basalts, in shales intruded by diabase. 2. Along the west side of the Santa Lucia Range in the San Simeon Quadrangle near Marmolejo Creek. 3. West of the Redington mine, the type section of the Knoxville. 4. West side of Berryessa Valley. 5. North of Wilbur Springs, Colusa County. 6. In the Nipomo and



GEOLOGIC MAP OF THE STANLEY MOUNTAIN REGION, NIPOMO QUADRANGLE, SAN LUIS OBISPO COUNTY, CALIFORNIA.

FIG. 7.—Geologic map of Stanley Mountain "Franciscan," Nipomo Quadrangle. Lithologic character is typically Franciscan but fossils are Knoxville.

Branch Mountain quadrangles, San Luis Obispo County. All of these localities, except No. 2, are readily accessible.

Radiolaria are not uncommon in the dark Knoxville shales, but only in one locality have they been observed in great abundance. This is in the Coalinga Quadrangle, on Taylor Creek, a branch of Jacalitos Creek. Here there is a moderately thick zone in dark shales containing *Aucella piochii* in which radiolaria are as abundant as foraminifera in some of the Miocene shales. These are well preserved as to outward form but, according to B. L. Clark, they are not in a state suitable for study as they have been rendered opaque by partial replacement by calcium carbonate.

In most of the area of the state volcanism ceased before the close of the Jurassic and permitted the deposition of predominantly fine-grained clastics, the waste from a greatly worn down land mass that had been lowered gradually by denudation during the deposition of the coarse clastics of the Franciscan. The Knoxville is a late phase in the cycle of deposition which resulted in a great thickness of coarse and fine clastics. In this phase of predominantly fine sediments depositional and environmental conditions appear to have been more favorable for organic life; at any rate, fossils are reasonably abundant in the Knoxville shales.

THICKNESS

The thickest sections of the Knoxville are found in Tehama County, on the west side of the Sacramento Valley, where a maximum of 13,820 feet, as measured by automobile traverse, is reported on McCarthy and Redbank creeks.[124] Unquestionably there is a great thickness of Knoxville, predominantly shale, in this region, but there are two very definite reasons why an accurate measurement of thickness is impossible. In the first place, there is a profound fault in the midst of the Knoxville, on Redbank Creek and an unnamed creek at the south, as shown by a zone of crushing and shearing fully 1,000 feet wide. The writer has not done enough field work in this region to determine the effect of the fault but it is clear that an accurate section can not be measured across this strong zone. In the second place, the base of the Knoxville shale is not exposed, being obliterated by a great sill of serpentine. The thickness of the Knoxville in Tehama and Glenn counties is undoubtedly great, probably in excess of 10,000 feet, but, for the reasons given, it can not be measured with any degree of accuracy. Only partial sections are exposed in the northern Coast Ranges west of the broad strip along the edge of the Sacramento Valley.

Because of strong folding and faulting in the Coast Ranges between San Francisco Bay and Santa Barbara only incomplete sections of the Knoxville are exposed, and the maximum thickness is unknown. The thickest section known to the writer (approximately 4,000 feet) is that north of Cuyama River, but here more than half the thickness is made up of volcanic rocks. Between 2,500 and 3,000 feet of fossiliferous Knoxville shales and sandstones are present east of

[124] F. M. Anderson, "Knoxville-Shasta Succession in California," *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 1242–43.

Priest Valley and Waltham Canyon, in eastern Monterey County, but the total thickness is unknown since the beds are bounded on the west by a fault and unconformably overlain by the Lower Cretaceous on the east. Fairbanks reports "more than 3,000 feet" of "Toro" in the San Luis Quadrangle, but the greater part of this is Lower Cretaceous. There is an even greater thickness of "Toro" at the northwest, in the Adelaida and San Simeon quadrangles, but here also the greater part is Lower Cretaceous.

The Knoxville appears to be thicker north of San Francisco Bay, but a definite statment to this effect is not justified because of the incomplete sections in the central Coast Ranges.

DISTURBANCES DURING KNOXVILLE DEPOSITION

There were local disturbances during the deposition of the great thickness of shales commonly known as Knoxville, just as there were disturbances during the deposition of the Franciscan, but no angular discordances are known. In the Coast Ranges north of San Francisco Bay there is, locally, a conglomerate in the midst of the Knoxville that contains a few small pebbles of the Franciscan and the underlying part of the Knoxville. There is no angular discordance and the conglomerate grades laterally, both north and south, into sandstones and shales. It is thickest north of Bear Valley in Colusa County, but thins in a short distance south. It is also present in the Knoxville district in Napa County, where it has a maximum thickness of 200 feet (about half of which is sandstone) in the tunnel of the Reed quicksilver mine. Knoxville fossils occur below, in, and above this conglomerate. Like other conglomerates in the Knoxville, it is made up of small well rounded pebbles of black chert, quartzite, and porphyrites, in addition to the Franciscan and Knoxville débris. Knoxville conglomerates containing Franciscan débris have not been observed elsewhere in the Coast Ranges south of the Knoxville district. This conglomerate, like certain of those described in the Franciscan, indicates a local uplift on the margin of the geosyncline. There is no indication of any widespread uplift during the deposition of either the Franciscan or Knoxville.

ALTERATION OF KNOXVILLE

In general, the great bulk of the Knoxville shows little sign of alteration but in some localities it is greatly sheared and quite as slaty as the Franciscan shales. This is especially true of the belt of Knoxville west of the crest of the Santa Lucia Range where Knoxville fossils have been found in very strongly compressed slaty black shales intruded by sills of diabase, gabbro, and serpentine.

Intrusions of basic and ultrabasic rocks are numerous in the Knoxville throughout the state; they are not confined to the lower part, but occur high in the shale section. The shales are commonly baked and hardened on such contacts, but as a rule there is comparatively little development of pneumatolytic contact rocks. However, glaucophane and related schists formed from fossiliferous Knoxville shales may be observed in several places, notably in the Knoxville district about a mile northwest of the Reddington mine, east of Priest Valley, and west

of the crest of the Santa Lucia Range. Comparatively few of the many basic and ultrabasic rocks emplaced in the Franciscan caused the extensive development of schists. The formation of these contact rocks is a function of the amount of magmatic solutions accompanying any particular intrusive and available for pneumatolytic action after the conversion of the original peridotite into serpentine. As previously stated, it appears that the great bulk of these magmatic solutions were utilized in the process of serpentinization in the case of the intrusions which rose through a great thickness of sediments and were emplaced high in the Knoxville shales.

Although the formation of contact schists is not common in the Knoxville, there is positive evidence that they have been formed in a few places.

BASIC AND ULTRABASIC INTRUSIONS IN KNOXVILLE

Although the presence of intrusions of serpentine and related rocks into the Knoxville has little to do with the question of the age of the Knoxville or its relation to the Franciscan it will be discussed and the literature reviewed. Since the writer has stated his views on this subject previously[125] and has cited numerous concrete examples, he does not feel that such a discussion should be necessary as one can go into the field and observe the examples. However, since some have expressed doubts regarding this matter, and appear to believe it to be a new and heretical idea, the literature is reviewed to show, by the history of this controversy that there is ample precedent for the views expressed here and previously. It should be clearly understood that the writer is not citing the literature in order to bolster his own arguments, as it is a purely observational matter completely substantiated by numerous field relations, but simply for the benefit of those who are not familiar either with the literature or with the field evidence.

At the outset, it is necessary to define the type of intrusion meant. By the simple, unmodified term intrusion, the writer wishes to convey the idea of the emplacement of the igneous rock as a magma rising from the depths in a molten or plastic slate so that to-day it has essentially the same relation to the surrounding beds as it had at the time of its original emplacement. In other words, it is used in the ordinary sense. This is in contrast to a cold intrusion or piercement that has had its original emplaced position disturbed by diastrophic forces and has moved, generally upward, long after consolidation, as a cold, probably rather plastic mass into the crests of folds or along faults. Examples of both ordinary and cold intrusions are cited. The absence of glaucophane schists can not be regarded as a criterion for cold intrusion as most ordinary intrusions are unaccompanied by the development of pneumatolytic contact rocks.

Blake,[126] in 1855, clearly stated that the San Francisco sandstone (Franciscan)

[125] N. L. Taliaferro, "Geologic History and Structure of the Central Coast Ranges of California," *California State Min. Bur. Bull. 118*, Pt. 2 (1941).

[126] W. P. Blake, "Observations on the Characters and Probable Geological Age of the Sandstone of San Francisco," *Proc. Amer. Assoc. Adv. Sci.*, Vol. 9 (1855), pp. 220–22.

in the San Francisco Bay region, was intruded by serpentine. Becker,[127] in 1886, reached the remarkable conclusion that the serpentine and diabase in the Knoxville district, in the Knoxville formation, were altered sandstones and shales. As shown by the map accompanying Becker's quicksilver report,[128] the rocks intruded by the serpentine are Knoxville, in the sense used in this paper and not the upper, or Lower Cretaceous, part of the original Knoxville. The cross sections accompanying Becker's monograph show the correct relationships—the serpentine invading the Knoxville. However, Becker interpreted these relationships as a peculiar form of metamorphism. In this district, the type section of the Knoxville, the serpentine is not a cold intrusion as shown by the fact that it covers many square miles, and that many details of the contact may be observed and these show all the evidence usually considered as indicative of intrusion, such as numerous small apophyses from the main body, baked contacts, the occasional development of glaucophane schists, and extensive veining in the vicinity of the igneous rock. The evidence is clear and convincing; if the serpentine in the Knoxville, in the Knoxville district, is a cold intrusion, then all the serpentines, gabbros, and diabases in the Franciscan are cold intrusions. There has been no doubt in the minds of the geologists who have visited this region with the writer regarding the intrusive nature of the serpentine and diabase.

Kramm[129] described examples of the intrusion of serpentine into the Knoxville in the Knoxville district, as well as in other regions. He mentions the exposure of a contact between shale and serpentine in the Johnson shaft of the Knoxville mine. The writer has observed an excellent intrusive contact in the tunnel of the Reed mine. Kramm also described the intrusion of serpentine into Knoxville shales and sandstones in the Sulphur Creek district, in western Colusa and eastern Lake counties. Many examples also have been observed by the writer in this district.

The observed relations in the Knoxville and Sulphur Creek regions are well exposed and conclusive, but these are but two regions among many where basic and ultrabasic rocks are intruded into the Knoxville. An excellent example is near the head of Redbank Creek, in Tehama County, where the contact between serpentine and fossiliferous Knoxville shales is well exposed, very irregular, and marked by a wide zone of baking and veination.

Fairbanks,[130] in 1892, reported many examples of the intrusion of serpentine into the Knoxville:

[127] G. F. Becker, "Cretaceous Metamorphic Rocks of California," *Amer. Jour. Sci.*, 3d Ser., Vol. 31 (1886), pp. 348–57.

[128] *Idem,* "Geology of the Quicksilver Deposits of the Pacific Slope," *U. S. Geol. Survey Mon. 13* (1888).

[129] H. E. Kramm, "Serpentines of the Central Coast Ranges of California," *Proc. Amer. Philos. Soc.*, Vol. 49 (1910), pp. 315–50.

[130] H. W. Fairbanks, "The Pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges," *Amer. Geol.*, Vol. 9 (1892), pp. 153–66.

On Grindstone Creek, Colusa County, the Knoxville shales have been metamorphosed for a distance of a hundred feet, the bedding being obliterated and a noticeable hardening induced.

He also cited numerous other instances in Tehama and Colusa counties and described the effect of the intrusions on sandstones and shales containing *Aucella piochii.*

Turner[131] mentioned the intrusion of serpentine and diabase into Knoxville shales in the Mount Diablo region. This has not been verified by the writer; the relations here are not entirely clear and may be due to faulting.

Fairbanks[132] stated that the serpentines, gabbros, and diabases of the San Luis region intrude the Toro shales, which he regarded as equivalent to the Knoxville and of Lower Cretaceous age. The writer has examined these contacts and has mapped the Toro on the northwest in the Adelaida and San Simeon quadrangles. The Toro actually consists of two parts, separated by an unconformity; the lower is Upper Jurassic Knoxville, as shown by abundant fossils, and the upper is the Paskenta stage of the Lower Cretaceous. The lower Knoxville part is intruded by basic and ultrabasic rocks but the upper, Lower Cretaceous, part is not. The basal conglomerate of the Lower Cretaceous contains débris of the intrusives. A very excellent example of the intrusion of diabase into fossiliferous Knoxville shales occurs in this region, especially in the San Simeon Quadrangle, along the west side of the Santa Lucia Range, where diabase occurs as a sill in the midst of a comparatively narrow belt of Knoxville shales. This relation may be seen on any of the ridges west of Burnett Creek, San Simeon Quadrangle, particularly between Spanish Cabin and Van Gordon creeks.

English[133] mentioned the intrusion of serpentine into the Cretaceous in the Table Mountain area southwest of Parkfield, Monterey County. He referred to Fairbanks' work in the San Luis Quadrangle and evidently used Cretaceous in the same sense. This area has been mapped, in part, by the writer. The northern end of Table Mountain is clearly a sill intruded into Knoxville shales. Erosion has removed the shales above the sill, but they are well exposed beneath and clearly indicate that both the sediments and the serpentine have been folded into a syncline. These relations are shown on section I of the geologic structure sections accompanying the writer's paper on the central Coast Ranges.

In addition to the examples given previously, the writer has observed the intrusion of serpentine, gabbro, and diabase into the Knoxville in at least eight other widely scattered districts, most of which are readily accessible.

In the Priest Valley Quadrangle, east of Priest Valley, in Sec. 11, T. 20 S., R. 12 E., a complex of serpentine, gabbro, and diabase intrudes fossiliferous

[131] H. W. Turner, "The Geology of Mount Diablo, California," *Bull. Geol. Soc. America*, Vol. 2 (1891), pp. 383–402.

[132] "San Luis, California," *U. S. Geol. Survey Geol. Atlas Folio 101* (1904).

[133] W. A. English, "Geology and Oil Prospects of the Salinas Valley—Parkfield Area, California," *U. S. Geol. Survey Bull. 691-H* (1918), pp. 232–33.

Knoxville shales and sandstones, and locally has converted them into glaucophane schists. Copper-stained calcite veins extend outward away from the intrusion into the shales; fossils have been obtained from baked shales between veins.

On Mustang Ridge, also in the Priest Valley Quadrangle, serpentine intrudes fossiliferous Knoxville shales on both sides of the San Andreas fault. There are many places on this ridge where the relations are clear and unmistakable.

North of the Cuyama River there are excellent exposures of intrusive contacts of serpentine in fossiliferous Knoxville shales. Abundant fossils have been collected from baked and pyritized shales. Ten miles south, on Tepusquet Creek, similar relations have been observed.

In the Santa Cruz Mountains, west of Gilroy, ammonites, aucellas, and belemnites have been collected from Knoxville shales clearly intruded by serpentine.

Near the St. Johns quicksilver mine north of Vallejo, the writer has mapped intrusive contacts and has collected Knoxville fossils within a short distance of serpentine.

On the west side of the Berryessa Valley there are many examples of the intrusion of both serpentine and diabase, both as sills and plugs, into fossiliferous Knoxville sediments. One of the best examples is found on Putah Creek, between Jerd and Cement creeks, 4–5 miles west of the edge of Berryessa Valley, where abundantly fossiliferous Knoxville shales are completely surrounded and intimately injected by serpentine. *Aucella mosquensis* and *A. piochii* are abundant in these beds.

From 2 to 4 miles north of Middletown, on the highway to Clear Lake, there are several excellent and well exposed intrusive contacts of both serpentine and diabase into black baked Knoxville shales and basic tuffs.

West of Paskenta, on Thoms Creek and at the north, serpentine intrudes the Knoxville and transgresses at least 7,000 feet of fossiliferous sediments.

A photograph of the excavation for the Greek Theater at the University of California, Berkeley, shows serpentine intrusive into Knoxville shales. This contact is not exposed at present, but there are many examples of intrusive contacts in the hills back of Oakland.

Many of the localities mentioned are readily accessible and it is only necessary to observe the relations in the field to realize that the basic and ultrabasic rocks, regarded by some as confined to the Franciscan, commonly intrude all parts of the Knoxville. The San Simeon Quadrangle, the Paskenta district, Redbank Creek, and the Knoxville district are exceptionally good examples.

Cold intrusions of serpentine into Knoxville and later beds have been observed in a number of places. Almost without exception, the plastic serpentine has carried up with it other types of Franciscan rocks, sandstone, cherts, basalts, and schists.

An excellent example of a cold intrusion of serpentine into both Knoxville and Paskenta sediments is found in the Adelaida Quadrangle between Josephine School and Black Mountain. Here greatly sheared serpentine has been squeezed

into the crest of an overturned and thrust-faulted anticline; blocks of chert, sandstone, and basalt have been carried up with the serpentine. About a mile northwest along the same fault the serpentine has been sheared into Miocene sediments and volcanics. This serpentine belt can be traced continuously for 3 miles, in which distance it has been squeezed into Knoxville, Paskenta, and the Miocene.

Along the north side of Antelope Valley, Cholame Quadrangle, there is a long belt of serpentine squeezed into either Knoxville or Paskenta shales and sandstones along the crest of a faulted anticline. There is a continuous zone of serpentine (and other Franciscan rocks) 4 miles long and there are here and there discontinuous areas along the same fault for an additional 4 miles northwest, at least as far as the Cottonwood Pass highway. Blocks of chert and sandstone have been carried up with the serpentine. This area has been described and mapped by Arnold and Johnson,[134] and by English.[135]

The entire Mount Diablo Franciscan, made up of serpentine, diabase, and various types of sediments, is a great piercement into a faulted anticline. In a sense this Franciscan mass is a cold intrusion of heterogenous types rendered somewhat plastic by the presence of serpentine and great pressure.

There are a number of examples of cold intrusions of serpentine into Miocene sediments along faults. The clearest case observed by the writer occurs along the Suey Creek fault in the Nipomo Quadrangle where there are several long but very narrow belts of intensely sheared serpentine in the midst of siliceous middle Miocene sediments. One zone is more than $\frac{1}{4}$ mile long and rarely more than 20 feet wide. Blocks of sandstone and chert have been brought up with the serpentine in a few places. In this locality, the serpentine has not had to rise any great distance above its original position as the Miocene rests on a basement of Franciscan.

No difficulty is encountered in differentiating between ordinary and cold intrusions, provided careful mapping is done in the area; casual inspection is not sufficient in many places, however. For example, a brief examination of some parts of the cold intrusion north of the Antelope Valley might lead to the conclusion it was an ordinary intrusion; it is only when the entire area is examined that its true nature becomes apparent.

There is another type of serpentine body, descriptions of which have not been published, that might be mistaken either for an ordinary or a cold intrusion, unless carefully studied and mapped. These are the gigantic land-slide types, almost wholly made up of serpentine, that occur here and there in the Paskenta stage of the Lower Cretaceous. Naturally, such serpentine slides occur in the vicinity of large intrusive bodies which supplied the material to the slides. The best examples known to the writer occur in western Colusa County, southeast of Wilbur

[134] R. Arnold and H. R. Johnson, "McKittrick-Sunset Oil Region, Kern and San Luis Obispo Counties, California," *U. S. Geol. Survey Bull. 406* (1910), p. 33.

[135] W. A. English, "Geology and Petroleum Resources of Northwestern Kern County, California," *ibid., Bull. 721* (1921), pp. 8, 9.

Springs. This area has been mapped by Schlocker and Owens,[136] graduate students at the University of California, under the direction of the writer. In this area there are a number of serpentine bodies some of which are clearly sedimentary, some clearly intrusive, and some of doubtful character. The great body that extends north and northwest of Wilbur Springs is clearly intrusive, as shown by details of contact and metamorphism of adjacent beds. The thick body of serpentine that is exposed along State Highway 20, between the bridge over Bear Creek and the quarry just above and south of Bear Creek, is clearly sedimentary. This lies wholly within the Paskenta and, locally, is the basal conglomerate of the Lower Cretaceous. It consists of several thousand feet of serpentine débris, blocks, boulders, and flakes, with minor amounts of Franciscan and Knoxville detritus and here and there a thin interbedded lens of shale. Only here and there can the bedding be seen on the outcrop but on aereal photographs, on the scale of 1 to 20,000, the bedding is conspicuous. The largest clearly sedimentary body is about 5 miles long and 1 mile wide. Both toward the north and south it grades laterally and fingers into Lower Cretaceous sandstones and shales. On the west, it rests on Knoxville sediments and serpentine; on the east it grades upward into ordinary Paskenta sediments with several thin lenses of serpentine débris interbedded with the sediments. These thin lenses are made up of shales colored green by serpentine flakes with scattered blocks of serpentine up to 10 feet in diameter, and with débris derived from the Franciscan and Knoxville. One of those thin zones, interbedded with Paskenta sandstones and shales, can be traced for a distance of about 6 miles; it is about 5,000 feet stratigraphically above the base of the Lower Cretaceous. Thick breccias made up of all types of Franciscan and Knoxville débris, up to 15 feet in diameter, occur in the basal Lower Cretaceous in other parts of the state. These serpentine breccias will be illustrated and more fully described in a future paper on the Upper Jurassic-Lower Cretaceous contact.

These great serpentine breccias or landslides occur without exception in the vicinity of great and extraordinarily thick serpentine bodies; they all appear to be marine. They are not unlike the Miocene Big Blue north of Coalinga, but many are much thicker.

Sedimentary bodies of serpentine such as those described fortunately are not particularly common. Superficially they may resemble intrusive bodies, but careful inspection and mapping leaves no doubt as to their origin. They are the natural result of the exposure of thick intrusive bodies of serpentine that were uplifted and exposed to erosion. Anyone familiar with the present exposures of serpentine realizes the ease with which great masses of serpentine will slide downward over adjacent lowlands. This is well illustrated about the serpentine body northwest of Coalinga.

136 Julius Schlocker and J. S. Owens, "Geology of Parts of Colusa and Lake Counties, California," unpublished master's thesis, University of California Library, 1941.

Relation between Franciscan and Knoxville

As shown in the historical review, the frequently reported unconformity between the Franciscan and Knoxville is due to the confusion between the restricted Upper Jurassic Knoxville and the Lower Cretaceous. Originally the term Knoxville was applied to the Franciscan, Knoxville, and Lower Cretaceous in the vicinity of the quicksilver mines in the Knoxville district. Gradually the name was restricted to practically all the dark shales above the Franciscan and below the Upper Cretaceous. For a long time no distinction was made between the Upper Jurassic and Lower Cretaceous parts of the original Knoxville and even since the distinction has been recognized the two frequently have been confused.

There is an unconformity at the base of the Lower Cretaceous, in places, but not everywhere, marked by a basal conglomerate. In most places, especially in those regions along the west side of the Great Valley of California which have been most frequently studied and which lie near the center of the geosyncline, the movements between the Upper Jurassic and the Lower Cretaceous were not sufficiently severe to uplift and remove any great amount of the Knoxville before the deposition of the Lower Cretaceous. In fact, in this general region, deposition was practically continuous in some places with strong local movement in others. However, on the north in northern Tehama County and westward in the Coast Ranges, these movements were more pronounced and in many places a large part or even all of the Knoxville was removed and the basal Lower Cretaceous beds rest directly on the Franciscan. The frequently mentioned unconformity between the Franciscan and the Knoxville actually is the unconformity between the Franciscan and the Lower Cretaceous.

There is no unconformity between the Franciscan and the Upper Jurassic part of the original Knoxville; there is no basal conglomerate at the supposed base of the Knoxville containing débris of the Franciscan. As previously mentioned, there is a local conglomerate well up in the Knoxville that contains a small amount of débris of the Franciscan, but it also contains débris of the underlying part of the Knoxville, especially the impure, commonly fossiliferous, limestones present in many places in the shales. This conglomerate, and those in the Franciscan, represent local disturbances on the border of the late Jurassic syncline; they do not indicate widespread movements that affected, or even greatly modified, the basin of deposition. Within a mobile belt, such as the Coast Ranges of California, a geosyncline of the magnitude of that in which the Franciscan and Knoxville were deposited probably could not go through its cycle of deposition, including strong volcanic activity and igneous intrusion, without experiencing local disturbances, especially along its borders.

The presence of a great unconformity between the Franciscan and the Knoxville almost has become an established fact in the literature, but the writer has no hesitation in stating that this is a mythical unconformity that exists only in the literature and not in the field. All of the reported unconformities have been visited; they have proved to be either non-existent or the unconformity at the

base of the Lower Cretaceous. Repeatedly the writer has gone into the field as a result of rumors regarding this unconformity, but thus far he has been unable to find any evidence to substantiate the rumors or the literature; the unconformity between the Franciscan and the Knoxville is as elusive as the pot of gold at the end of the rainbow.

For a number of reasons the relations between the Franciscan and the Knoxville are obscure; indeed, if this were not the case there would be no Franciscan-Knoxville problem. Fault relations between them exist, but are not especially common; both are largely made up of sediments and both yielded in the same manner during the frequent periods of folding and faulting since their deposition. Faults are much commoner between various members of the Franciscan, as between volcanics or intrusives and sediments than between Franciscan and Knoxville. In this connection, the writer wishes to comment briefly on a statement that has come to his attention recently.[137] He does not wish to criticize an abstract, but there is a statement that is not wholly in accord with his observations.

> Evidence is presented which indicates that the contact between the Knoxville and Franciscan is a fault having a displacement of many thousands of feet, resulting in the concealment of the basal Knoxville beds throughout the entire area.

The writer has crossed the area along the west side of the Sacramento Valley, both to the north and south of Willows, many times, both by automobile and on foot, and feels that he must question this rather sweeping statement. In the first place, he wishes to raise the question as to what is meant by Franciscan in this region. Almost everywhere along this side of the valley the Knoxville is in contact with a very wide belt of serpentine. In a great many places, some of which the writer has referred to previously, there is very positive evidence that the serpentine is intrusive into the Knoxville. Furthermore, there are large areas of Knoxville shale included within the serpentine west of the main contact. This great body of serpentine can not be referred to as "Franciscan," as that term is generally used, since it clearly intrudes the Knoxville. It is quite true that the contact between the serpentine and the Knoxville is a fault in several places both north and south of the latitude of Williams but this is not the case everywhere. In northern Glenn County the contact is a high-angle thrust fault that dips westward 60°–65°; in central Colusa County, where the writer has mapped the contact on a scale of 1 to 20,000, it is a vertical fault that passes southward into the Knoxville and Lower Cretaceous. On Redbank Creek the contact is clearly intrusive. Although there is strong faulting along much of the west side of the Sacramento Valley it is not everywhere between the serpentine and the Knoxville. It is the wide belt of serpentine that obscures the relation between

[137] P. W. Reinhart, "Cretaceous, West Side Sacramento Valley North of Willows" (abstract), Program 18th Ann. Meeting, Pacific Section, *Amer. Assoc. Petrol. Geol.*, p. 4, Los Angeles, October 16, 1941.

the Franciscan and the Knoxville, along the west side of the Sacramento Valley, rather than faulting.

Probably the chief reason for the obscure relation between Franciscan and Knoxville is the presence of the thick, sill-like intrusion of the serpentine-gabbro-diabase complex, previously referred to, along the west side of the Sacramento Valley. This intrudes the upper part of the Franciscan and the lower part of the Knoxville, but in some places it is wholly within either Knoxville or Franciscan.

It is only where this sill thins and lies within the Franciscan that the true relations are apparent.

The best locality in which to observe the true relations between Franciscan and Knoxville, on the west side of the Sacramento Valley, is on the west side of the Wilbur Springs anticline 2 miles northwest of the Manzanita quicksilver mine which is 3,200 feet due west of Wilbur Springs, in western Colusa County. On the crest of the anticline are exposures of typical slightly slaty Franciscan shales and sandstones, here and there with basalts and radiolarian cherts. Toward the southwest, upward in the section, these are followed by the sill of serpentine, previously referred to, which here has thinned to 1,200 feet. Above the sill are approximately 2,000 feet of steeply tilted, southwestward-dipping, pillow basalts with interbeds of red radiolarian chert and black shale identical with that in the Knoxville above. These pillow basalts and sediments have, in places, been intruded by serpentine and by small plugs of basalt or diabase, most of which are greatly autobrecciated as though intruded into wet sediments. Toward the top of the basalts, a few hundred feet east of Sulphur Creek, the pillow basalt flows are thinner and are interbedded with dark clay shales and with basalt and diabase agglomerates identical in composition with the plugs already mentioned. Knoxville fossils, aucellas and belemnites, were found by J. S. Owens in shales and agglomerates *below* pillow basalt flows. Upward in the section both the basalt flows and agglomerates die out and there is an unbroken, southwestward-dipping section of typical fossiliferous Knoxville shales and sandstones. In this region there is a zone more than 600 feet thick, containing flows of basalt and many layers of agglomerate interbedded with dark clay shales and sandstones and containing Knoxville fossils, that is transitional between what is, without exception, regarded as typical Franciscan and typical Knoxville. The contact between Franciscan and Knoxville is gradational.

A similar gradational contact occurs between Franciscan and Knoxville west of the southern end of the Berryessa Valley, north of the road between Monticello and St. Helena. Exposures, however, are not as good as in the Wilbur Springs district. In this region diabase and basalt breccia necks are intruded into fossiliferous Knoxville shales and sandstones.

In western Monterey County, Cholame Quadrangle, about 3 miles north-northeast of Parkfield, on Antonio Creek, the contact between Franciscan and Knoxville shales, below the Table Mountain serpentine sill previously mentioned, is exposed, here and there, for a distance of nearly 2 miles. Actually, there is no

contact in the true sense of the word. Pillow basalts and radiolarian cherts appear beneath the shales, but they are interbedded with dark clay shales identical with those above.

In the San Simeon Quadrangle northeast of Burnett Creek, and in the Bryson Quadrangle at the north, on the road between San Simeon and Jolon, it is impossible to map a definite contact between typical Franciscan and fossiliferous Knoxville shales, except where the contact is a fault.

Thus, where it is possible to observe the contact between Franciscan and Knoxville, and where a thick sill of serpentine does not intervene, it is found to be gradational. No unconformity exists and there is no basal conglomerate as so frequently has been reported.

If there is no unconformity between the Franciscan and the Knoxville, and if the contact is gradational, the questions at once arise as to just what is meant by the two terms, and if this gradational contact occupies approximately the same time interval throughout the state.

As has been shown previously, the Franciscan is recognized by certain distinctive lithologic types, such as pillow basalts, vesicular basalt flows, breccias, and tuffs, radiolarian cherts, arkosic sandstones, foraminiferal limestones, and the pneumatolytic contact rocks. As usually described, the Knoxville is characterized by a very considerable thickness of dark clay shales and dark clayey arkosic sandstones that carry a late Upper Jurassic (Tithonian) fauna. However, in neither case can it be said that the lithologic character is unique. The supposed characteristic lithology of the Franciscan is not peculiar to it even in California as the Sierra Nevada pillow basalts and radiolarian cherts occur in the Mississippian, in the Amador (late Middle or early Upper Jurassic), and in places in the Mariposa; all of these are pre-Franciscan. Even the pneumatolytic contact rocks are not confined to the Franciscan since, also in the Sierra Nevada, especially along the Cosumnes River, there are actinolite-albite-quartz-sphene schists, derived from the Amador, on the borders of serpentine masses. The Knoxville in its general appearance certainly is not unique, as it closely resembles parts of the Franciscan and contains some of its supposedly characteristic lithologic types, and as much of it is lithologically identical with the Lower Cretaceous. Aside from the stratigraphic position of the Franciscan and Knoxville a distinctive feature of both is the sequence that has been described previously and which will be summarized later. The features by which the Franciscan and Knoxville may be recognized, aside from their fauna and stratigraphic position, are geographic position and lithologic features and the sequence in which the lithologic types appear. These characteristics serve to differentiate both from other similar lithologic units in the state.

Additional light is thrown on these problems by the beds north of the Cuyama River that are lithologically similar to both the Franciscan and the Knoxville, and which contain a fauna supposed to be equivalent to that in typical Knoxville shales in the northern Coast Ranges, especially along the west side of the Sacra-

mento Valley. If, in naming the beds north of the Cuyama River, the procedure customary in the northern Coast Ranges were followed great confusion would result. Although the distinction between Franciscan and Knoxville in the northern Coast Ranges is supposed to be both faunal and lithologic it is essentially the latter. The practice in the past very definitely has been to place only shales, sandstones, and conglomerates in the Knoxville and intrusives, volcanics, cherts, and contact schists in the Franciscan. This practice is indefensible as it is based on preconceived ideas and not on observed relations. If, in the case of the beds north of the Cuyama River, lithologic character alone was the basis of distinction, only the few hundred feet of dark shales and thin sandstones above the radiolarian cherts and basalts and below the unconformably overlying Lower Cretaceous would be Knoxville. What then could we call the dark shales and thin sandstones, containing a typical Knoxville fauna, that are interbedded with and lie below the cherts and basalts? Their fauna is Knoxville, but their lithologic character is Franciscan. These beds clearly indicate that, in this region, volcanism, with the attendant formation of red radiolarian cherts, continued practically to the close of Knoxville deposition. In northern California, volcanism ceased at an earlier date and permitted the accumulation of a thick section of shales and sandstones. In one region a typical Knoxville lithology resulted while, in another region, a typical Franciscan lithology was being formed contemporaneously. Thus, the transition between a typical Franciscan and a typical Knoxville lithology would transgress time if followed from one part of the state to the other.

What name or names should be used? The writer has no intention of proposing new names as he feels that the present terms, Franciscan and Knoxville, have been too frequently used to be replaced. It is believed that, in mapping in local areas, no difficulty will be encountered as it will be possible to divide the rocks into members, or possibly even formations, by use of local names for the individual units. However, he does propose that the term Franciscan-Knoxville be used to designate that group of rocks, having the lithologic character, stratigraphic position, and sequence previously described. The Franciscan-Knoxville group, as here defined, represents a continuous cycle of deposition, except for minor local disturbances on the borders of the basin, in a great and long-enduring geosyncline that came into existence after, and as a result of, the Nevadan orogeny. It is confined to the late Upper Jurassic, probably entirely to the Tithonian, and hence is confined to a relatively short time interval; it can not be considered as equivalent to all of the lower Mesozoic as has been thought heretofore. It is a stratigraphic unit of considerable value and represents a very important chapter in the development of the Coast Ranges of California. The Knoxville is simply an upper shaly phase of the Franciscan.

Franciscan-Knoxville Geosyncline

The Franciscan has been shown to be younger than the lower Kimmeridgian and older sediments and volcanics and than the Nevadan orogeny that deformed

these beds. There is definite evidence that the Mariposa and older Mesozoic sediments of the Sierra Nevada, Klamath Mountains, and southwestern Oregon, were deposited in a geosyncline whose western border was a land mass located on the site of the western part of the present Coast Ranges. The great abundance of shale in the upper part of the Mesozoic rocks of the Sierra Nevada, Klamath Mountains, and southwestern Oregon, indicates that the land mass from which these rocks were, in part, derived had been worn down to an area of low or moderate relief. The Nevadan orogeny that intensely folded, thrust-faulted, and dynamically metamorphosed these lower Kimmeridgian and older rocks, slightly uplifted the ancestral Sierra Nevada, and their continuation through the Klamath Mountains into southwestern Oregon, depressed the region of the present Coast Ranges, and greatly rejuvenated and uplifted a long, and probably wide, land mass west of the present coast line. Thus it appears that the continent was expanded westward at this time. The sea invaded the depressed area between this western land mass and the ancestral Sierra Nevada, probably for the first time in the Mesozoic. In the geosyncline thus created, and which extended from Santa Barbara County northward a considerable distance into southwestern Oregon, the Franciscan was deposited. The creation of this geosyncline and the beginning of Franciscan deposition marks the beginning of the readily decipherable history of the Coast Ranges.

This rejuvenated and uplifted land mass west of the present coast line marked the western boundary of the geosyncline and it was from this high and rugged area that the coarse arkosic sandstones were derived. It is known that mechanical disintegration predominated over chemical decomposition and it is inferred that the coarse arkosic material was derived from a high rugged terrane under rigorous climatic conditions, probably a cold climate and abundant precipitation in the higher region, and carried by streams of high gradient into the basin on the east, and present site of the Coast Ranges. Under these conditions this type of material would accumulate rapidly in the geosyncline, where sinking appears to have kept pace with deposition. However, deposition did not cause the sinking, at least in the beginning; the initiation of the geosyncline was the result of diastrophism at the time of the Nevadan orogeny.

It is possible to outline the general extent of the geosyncline but, naturally, the minor details of configuration of the coast line are unknown. Any evidence regarding such minor details is buried beneath the later sediments and alluvium of the Great Valley of California on the east and beneath the Pacific Ocean on the west.

The great land mass from which a large part of the clastic sediments of the Franciscan and Knoxville was derived, and which was gradually worn down and later foundered, now lies beneath a great depth of water. The materials making up this great land mass were of continental type—sial. Therefore, if the foregoing is true, continental rocks must underlie the edge of the present deep Pacific basin. Fortunately seismology offers definite evidence on this point. A number of earth-

quakes, with epicenters off the California coast, as well as throughout the state, have been recorded at widely scattered seismographic stations from Alaska to southern California.[138] All of the known epicenters have been plotted and it is found that they do not extend for more than 110 miles off the coast of northern California; within this distance they are numerous but they stop abruptly at this line. This prevalence of earthquakes to within 110 miles off shore, coupled with their complete absence outside this line, led Byerly[139] to conclude

> that the San Andreas fault reaches the border of the continental mass near 42° N., 126° W. and that the stresses leading to earthquakes, which are common on the continent, do not persist in the ocean floor.

The position of numerous epicenters of earthquakes indicates that continental rocks extend for 110 miles west of the present coast line, even though now at a depth of more than 10,000 feet below sea-level. Seismologic evidence, therefore, is certainly not in conflict with, and even affords support for, the writer's concept of a former land mass of continental rock types west of the present coast line.[140]

Depositional History of Franciscan-Knoxville Group

GENERAL STATEMENT

The great similarity in the clastic sediments of the Franciscan throughout its extent indicates relatively uniform conditions of derivation and deposition in a very wide area; this is also true of the Knoxville although the type of sediment differs somewhat. The Franciscan consists of dominantly coarse and the Knoxville of dominantly fine clastics. The essential difference between them, in a broad sense, is not a difference in kind of sediment, but in the relative proportions of the different types. With the exception of the volcanics and chemical sediments, the clastic sediments show a definite decrease in average grain size with the passage of time. This is interpreted as indicating a gradual wearing-down of the land mass from which they were derived and, consequently, a lessening in the gradient of the streams. It is also possible that the gradual decrease in elevation through erosion, and the resulting changes in relief and configuration of the land mass brought about a change from predominant mechanical disintegration to a condition in which chemical decomposition, resulting in abundant clays, played an increasingly important rôle. In a number of places the Franciscan becomes increasingly shaly in its upper part and gradually passes into the predominantly shaly Knoxville. The gradual wearing-down of the source of the detritus making up both the Franciscan and Knoxville resulted in a decrease in coarse and an increase in fine clastics supplied to the basin of deposition.

[138] P. Byerly, "Earthquakes Off the Coast of Northern California," *Bull. Seis. Soc. America*, Vol. 27 (1937), pp. 73–96.

[139] *Idem*, "Seismicity of the Northern Pacific Coast of the United States," *Bull. Geol. Soc. America*, Vol. 51 (1940), pp. 256–57.

[140] The writer is indebted to Perry Byerly, professor of seismology, University of California, Berkeley, for reading, revising, and approving the statement regarding seismologic evidence.

As has been shown, there were occasional local interruptions in this orderly progression, due to movements on the western border of the basin, resulting in local intraformational conglomerates. Also the outbreak of volcanism, after continued downsinking and the deposition of a thick prism of sediments, modified but did not essentially change this rather orderly depositional cycle.

The writer has divided the Franciscan-Knoxville sequence into four stages[141] that merge into each other. There are many local irregularities and the four stages can not be regarded as formations that can be traced throughout the extent of these beds because of many complexities. For instance, volcanism neither began nor ended at the same time everywhere, nor was it of equal intensity throughout the sinking geosyncline. Furthermore, there must have been great initial irregularities in elevation and in stream distribution in the land mass from which the sediments were derived. There is some slight evidence, from the character of the sediments, that the land mass was either lower or farther from the present coast line west of Cape Mendocino and Eureka than on the north and south. However, it is believed that the proposed division, with all its imperfections and generalizations, serves a useful purpose and aids in clarifying many obscure relationships. These stages are as follows.

FIRST STAGE, LOWER FRANCISCAN

Arkosic sandstones, representing the rapid, chiefly mechanical degradation of a recently uplifted rugged land mass on the west, were deposited in a sinking basin between the western land mass and the recently uplifted, ancestral Sierra Nevada on the east. The ancestral Sierras do not appear to have attained any appreciable elevation since débris of typical Sierran basement rocks is not recognizable. However, the unmetamorphosed surface sandstones and shales of the Mariposa, very similar in character to those in the Franciscan, may have been eroded and supplied a part of the clastic material. Volcanic outbursts were not common during this stage and few chemical sediments were formed.

SECOND STAGE, UPPER FRANCISCAN

This stage shows the beginning of widespread volcanism; continued deposition of arkosic sandstones but with many interdigitations of shale; maximum development of cherts and here and there foraminiferal limestones; beginning of the intrusion of basic and ultrabasic rocks accompanied by local formation of pneumatolytic contact rocks.

THIRD STAGE, UPPER FRANCISCAN AND LOWER KNOXVILLE

This was followed by continued deposition of coarse and fine clastics with shales becoming more abundant; waning of volcanism and marked decline in chemical sediments (cherts) except in local areas, such as north of the Cuyama

[141] N. L. Taliaferro (1941), pp. 126–27.

River in San Luis Obispo County and along the west side of the San Joaquin Valley where volcanic outbursts resulting in flows, tuffs, and breccias still continued, in many places accompanied by the formation of radiolarian cherts. Over most of the basin, waning volcanism was marked by local explosive activity rather than by numerous flows. Intrusion of basic and ultrabasic rocks, with the formation of contact schists, continued. This stage is, as a rule, thinner than the others. However, it may overlap and even continue through the fourth stage. A moderately abundant Knoxville fauna is present in places.

FOURTH STAGE, KNOXVILLE

Over most of the Coast Ranges this stage is characterized by fine clastics, silts, sandy shales, clayey sandstones; pebble conglomerates occur here and there. No volcanism or chert deposition occurred in northern California; volcanism and chert formation, however, continued almost throughout this stage in local areas. Intrusion of basic and ultrabasic rocks continued practically to the close of the Jurassic, the end of this stage. Pneumatolytic contact schists only rarely developed. An abundant Knoxville fauna is found in the sediments of this stage even where volcanism still continued.

Although there were many local variations and these stages can not be used as definite cartographic units, except in local areas, it is believed that they give an adequate and comprehensive picture of the ordinary sequence of events in the Coast Ranges of California during the closing stage of the Jurassic (Tithonian).

During these four stages a great but imperfectly known thickness of sediments and volcanics accumulated. The total maximum thickness probably was in excess of 30,000 feet. Interruptions in deposition and variations in thickness undoubtedly occurred, but there were certainly fewer and less marked interruptions and variations than during the Cretaceous.

Relation of Franciscan-Knoxville Group to Lower Cretaceous Diablan Orogeny

The Jurassic was brought to a close by a widespread uplift which affected, with greatly varying degrees of intensity, almost the entire Coast Range region and probably to an even greater extent the area west of the present coast. The ancestral Sierra Nevada appears to have been uplifted to some extent at this time as the Lower Cretaceous locally contains coarse débris of Sierran origin. Although there were rather widespread movements at the close of the Jurassic, and even strong uplift and considerable erosion in some places, the emergence was not complete over the entire basin and the Franciscan-Knoxville geosyncline was not destroyed. Resubmergence appears to have quickly followed uplift and the Lower Cretaceous was deposited in essentially the same geosyncline, although the major axis of the trough may have shifted slightly toward the east.

Along the zone that is now the west side of the Great Valley of California emergence was comparatively slight and in some parts of this zone deposition

may have been practically continuous. West of this zone, in the present Coast Ranges, the movements were more severe and there are strong overlaps and unconformities. There is a gradual northward overlap along the west side of the Sacramento Valley and, in northern Tehama County, the Paskenta stage of the Lower Cretaceous rests on Paleozoic rocks, the Franciscan-Knoxville group having been removed. Nowhere else along the west side of the Great Valley was the Knoxville removed completely prior to the deposition of the Lower Cretaceous, but in many places on the west, within the Coast Ranges, the Knoxville stage was completely removed. With the exception of northern Tehama County, there is no area within the Coast Ranges where any great thickness of Franciscan was removed before the deposition of the Lower Cretaceous.

In both the Diablo and Santa Lucia ranges the Lower Cretaceous overlaps onto typical Franciscan, the Knoxville stage having been partially or completely removed. In the southeastern part of San Benito County, in the center of the Diablo Range, fossiliferous Lower Cretaceous (Paskenta) sediments rest on typical Franciscan rocks, both igneous and sedimentary, without any intervening Knoxville. However, the basal Paskenta conglomerate contains abundant débris of the Knoxville, much of it little rounded and some of it containing Knoxville fossils, indicating the former presence of Knoxville sediments in this region. Since there is evidence of strong uplift and erosion in the Diablo Range, the writer has proposed the name Diablan for the orogeny between the Upper Jurassic and Lower Cretaceous in the Coast Ranges of California. This diastrophism, while insignificant when compared with the Nevadan orogeny or some of those that affected the Coast Ranges in the late Cretaceous and in the Tertiary, was much stronger than any disturbance during the deposition of either the Franciscan-Knoxville group, or the Lower Cretaceous. Locally, it caused uplift and erosion of at least 4,000 or 5,000 feet; it was stronger and more widespread than has been recognized previously.

Importance of Franciscan-Knoxville Group in Evolution of Coast Ranges

The creation of the Franciscan-Knoxville geosyncline and the deposition of the sediments in it marks the beginning of the decipherable stratigraphic and structural history of the California Coast Ranges. A very great thickness of sediments was deposited in this trough during the late Jurassic (Tithonian) throughout the Coast Ranges north of Santa Barbara. There is no evidence that this geosyncline was divided into two or more parts separated by land masses. The crystalline complex on which the Franciscan was deposited was uplifted and the Franciscan-Knoxville group stripped off over a part of the central Coast Ranges at a later date.

Although diastrophism took place at the close of the Jurassic, and was severe in the Coast Ranges, it only modified and did not destroy the geosyncline and the Lower Cretaceous was deposited in essentially the same trough. Movements

between the Lower and Upper Cretaceous further modified the geosyncline, but its real fragmentation did not begin until late Upper Cretaceous and was not completed until some time in the Eocene. An enormous thickness of late Upper Jurassic and Cretaceous sediments was deposited in this trough, thus creating, over much of the Coast Ranges, a thick prism of pliable rocks on which the later Tertiary sediments ordinarily rest. This great prism of sediments has yielded by folding and thrust faulting during the later diastrophism that has affected the Coast Ranges.

The main axis of the great and long-enduring Mesozoic geosyncline had the same general trend as the present Coast Ranges. The various Tertiary basins, however, which were mere remnants of this earlier and greater trough, were elongated at a marked angle both to the main axis of the Mesozoic geosyncline and the present trend of the coast line. The thick prism of sediments that accumulated in the Mesozoic geosyncline was of the greatest importance in the subsequent history of the Coast Ranges since these sediments conditioned the type of yielding and the character of the structures formed during later periods of folding.

Conclusions

The more important conclusions reached in the present paper are believed to be amply supported by all available evidence. These conclusions may be summarized as follows.

1. The Franciscan-Knoxville group was deposited in a great geosyncline that came into existence as a result of the Nevadan orogeny. This great trough extended uninterruptedly from Santa Barbara northward into southwestern Oregon. Several independent basins of deposition, separated by land masses, did not exist but deposition took place in a single great trough.

2. The major part of the detritus making up the Franciscan-Knoxville group was derived from a high and rugged land mass west of the present coast line. The change from the characteristic coarse arkosic detritus of the Franciscan to the predominantly shaly Knoxville was the result of the gradual wearing down of this land mass by erosion. Seismologic evidence shows that, at present, continental rocks—sial—extend 110 miles west of the coast of northern California. This is regarded as evidence supporting the concept of a land mass during the Mesozoic as it is hardly likely that such a great belt of continental rocks came into existence at a late date.

3. There is no unconformity between the Franciscan and Knoxville (Upper Jurassic part of the original Knoxville). In fact the conditions that resulted in the lithologic character considered typical of the Franciscan (pillow basalts, radiolarian cherts, intrusives, and pneumatolytic contact rocks) persisted almost until the close of the Jurassic in some parts of the state so that typical Knoxville shales were being deposited in one locality at the same time a typical Franciscan assemblage was forming in another. Wherever the evidence has not been obliterated

by intrusion or faulting, the Franciscan may be observed to grade upward into the Knoxville.

4. The Franciscan is not a group name of uncertain age and no stratigraphic value but, on the basis of sound stratigraphic evidence and meager faunal evidence, represents a comparatively narrow time range. The Franciscan and Knoxville together are Tithonian in age (late Upper Jurassic). The term "Franciscan-Knoxville group" is proposed for the entire depositional sequence that commenced with coarse and ended with fine clastics, together with the interbedded volcanics, chemical and organic sediments, intrusives, and pneumatolytic contact rocks.

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GEOLOGICAL NOTES

NEW TECHNIQUE FOR MEASUREMENT OF STRATIGRAPHIC UNITS[1]

BERNHARD KUMMEL, JR.[2]
Iowa City, Iowa

Various field techniques are employed by stratigraphers and structural geologists to measure stratigraphic units. Each method is particularly adapted to conditions that are influenced by the topography and structure of a region, the degree of accuracy required, and the purpose of the measurement. Hand level, Abney level, clinometer, barometer, tape, Brunton, and telescopic alidade are the most common instruments employed. The technique of strapping a Brunton compass to a rod, a so-called "Jacob staff," has been known for sometime.

In preparation for stratigraphic studies in the middle Rockies, N. D. Newell and the author studied the various methods and instruments used to measure detailed stratigraphic sections. These studies soon led them to eliminate all the aforementioned techniques except the last, namely, that of a Brunton strapped to a rod. This technique is undesirable, however, because the chances of damaging the compass are great and it is difficult to make the attachment between the Brunton and the rod secure.

By using the principle of the Brunton technique, an inexpensive Jacob staff was devised that served every need. This rod enabled the writers to obtain accurate results both easily and rapidly. Demonstration of this staff to several geologists, and their enthusiasm over it, prompted a brief description of this Jacob staff in the hope that others may find it useful in their stratigraphic work.

DESCRIPTION OF JACOB STAFF

The Jacob staff employed (Fig. 1, *A*, *B*) is a rod 5 feet long with a 7-inch quadrant attached to one end. The rod is marked, as is a stadia rod, in feet, half feet, and tenths of feet. A 90° arc is marked off on the quadrant, and a free-swinging pendulum is attached at its center. The quadrant is attached by screws flush with the end of the rod. On the upper surface of the quadrant, two small eye screws are attached, one at each end; these are used for sighting.

The rod can be made more compact and easy to handle, when not actually in use, by sawing the rod in half and attaching the sawed ends together with a hinge. Thus, the rod can be folded up to make a smaller article that can be easily placed in a knapsack.

The principle involved in the use of this rod is relatively simple. The rod is

[1] Manuscript received, December 21, 1942.

[2] University of Iowa.

tilted toward the exposed edge of the strata to an angle equivalent to the dip of the strata. At this position, the rod is perpendicular to the plane of the strata (Fig. 1, *C*). Then when one sights along the upper surface of the quadrant, or parallel with it at a lower position on the rod, the thickness of a particular sedimentary unit can be measured. If the sedimentary unit is more than 5 feet thick, a sight is taken along the top surface of the quadrant to a point in the line of

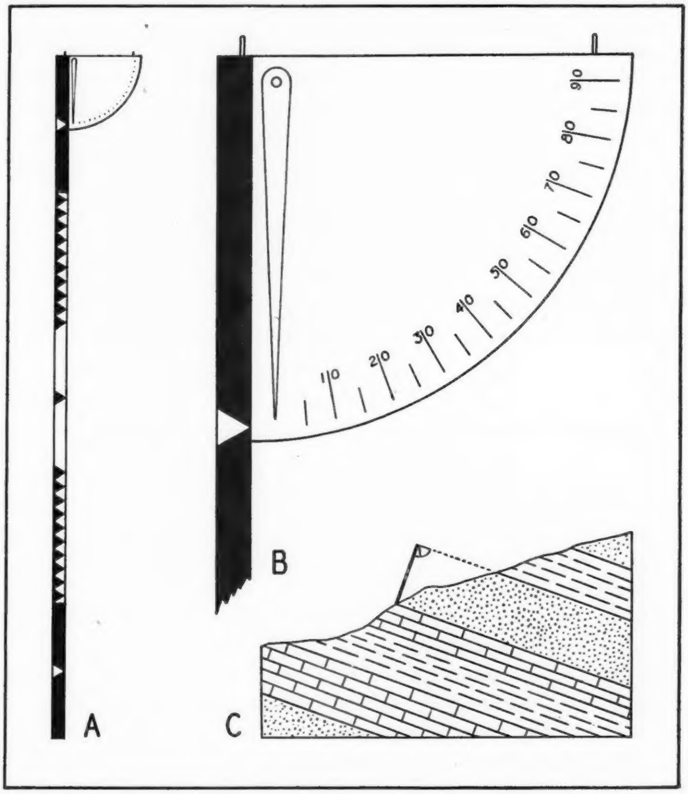

FIG. 1.—*A*, Jacob staff, *B*, enlarged diagram of quadrant, *C*, diagram illustrating use of staff.

sight which will, of course, be 5 feet higher stratigraphically than the base of the rod. The base of the rod is then placed at this point, and the procedure repeated until the thickness is ascertained. When a complete stratigraphic section is being measured, frequent dip readings should be made to check any variations which may occur in the dip. The traverse, needless to say, should be made in a line normal to the strike of the beds.

ADVANTAGES OF DESCRIBED STAFF

The Jacob staff as described has several significant advantages which merit attention. Measurements made by this method are accurate to within less than 5 per cent. Several sections have been re-measured specifically to test the staff's accuracy; sections have also been measured that had been previously measured by other geologists using different techniques. This method, in addition, facilitates constant checks on the strike and dip of strata, which vary within short distances in folded regions like the middle Rockies.

This Jacob staff is particularly valuable because of the completeness of the stratigraphical data which are obtained through its use. This is an important factor, since detailed stratigraphical data are necessary for much paleontological and sedimentational work. The plotting of measured sections on log strips helps greatly in the correlation and recognition of persistent traceable units, and also in facies changes not otherwise apparent.

Every instrument used to measure stratigraphic units is limited in its usefulness and efficiency by the structure and topography of the area in which it is employed; this Jacob staff is likewise limited by these factors. The staff can not be used to advantage in regions of nearly horizontal strata, but it is very practicable and efficient in regions of inclined and highly folded strata.

ONONDAGAN EQUIVALENT IN NEW MEXICO[1]

FRANK V. STEVENSON[2]
Chicago, Illinois

A hitherto unknown Devonian fauna from the Rocky Mountain province was discovered in the spring of 1942, by L. R. Laudon and A. L. Bowsher, as a by-product of their field research on the Mississippian stratigraphy of New Mexico. The locality of the new fauna is the Mockingbird Gap area, of the San Andres Mountains, in the southern-central part of the state.

Outstanding in the collection, which was kindly turned over to the writer for study, are seven excellently preserved specimens of *Paraspirifer* cf. *acuminatus*. The collection also contains several chert fragments, with numerous specimens of *Tentaculites* standing out on the surfaces. Several of these fragments have been sectioned, and were found to contain many more *Tentaculites* and a relatively small number of diminutive gastropods. One large *Spirifer*, unidentified as to species, was also found in the chert. This is the first known occurrence of Devonian chert in New Mexico.

Because the collection was made incidental to the Mississippian work, no notes are at present available on the thickness of these Devonian beds or on

[1] Manuscript received, January 2, 1943.

[2] Walker Museum of Paleontology, University of Chicago.

their contact with the overlying Devonian Sly Gap formation, which is found directly below the Mississippian in the San Andres Mountains.

The Devonian Canutillo formation has not been found north of Rhodes Canyon, which is approximately 100 miles south of Mockingbird Gap. It is thus logical to assume that this new fauna represents a new Devonian horizon, or possibly, but less likely, hitherto unknown sediments representing early Canutillo time. Should the latter prove to be the case, a definite age may be assigned to the Canutillo in place of its present equivocal one. It will be necessary, of course, to make a detailed study of the Mockingbird Gap area to determine the relationship of these apparently extremely local strata to the better known Devonian sediments of New Mexico.

Shortly after the receipt of this significant Onondagan fauna, the writer attempted to visit the area, accompanied by Professor J Harlen Bretz of the University of Chicago. On arriving in Alamogordo, New Mexico, however, they were informed that the entire central and northern Tularosa basin, of which the San Andres Mountains comprise the western boundary, was in a military reservation. It was therefore impossible to obtain admission to this area. Upon cancellation of this restriction, the writer proposes to conduct such field and laboratory work as may be required to solve this interesting stratigraphic and paleontologic problem of the Devonian of the Southwest.

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DISCUSSION

CLASSIFICATION OF OIL RESERVOIRS[1]

H. R. LOVELY[2]
Retford, Nottinghamshire, England

The criticism by Wilson[3] of the present use of the comprehensive phrase "stratigraphic trap" to describe all reservoir closures that are not deformational is timely, in view of the ever-increasing attention which is now being given to the detection of such oil accumulations, particularly in the United States.

Perusal of recent literature on the future trends in oil-finding shows definitely that the leading geological opinion is unanimous in stressing the importance of the so-called stratigraphic-trap type of oil reservoir for providing a large part of the future production in the United States of America. Articles on those principles of physical geology dealing with sedimentation are of frequent occurrence, and geologists are warned to become less "structure-minded," to appreciate the fundamentals of their science, and take a wider view of the processes of oil migration and accumulation. In these circumstances, it becomes essential to evolve a geological nomenclature which adequately describes and differentiates the various traps now included under the term "stratigraphic." As Wilson so truly points out, there is no distinction made at present between an oil trap formed by the actual lensing-out, and disappearance from the stratigraphical column, of a particular reservoir bed, and a trap formed within the same bed by virtue of local variation in porosity, permeability, cementation, *et cetera*. This first case is undoubtedly a stratigraphic trap, but can this term be accurately applied to the second one?

The writer is of the opinion that this difficulty could be avoided by the introduction of another class of trap to include all cases covering varying physical and chemical properties of the constituent rock, and to call this class "Lithologic" traps.

There would thus be three types of oil reservoir according to the following geological classification.

1. Structural, including all traps formed by actual deformation of the earth's crust by either folding or faulting
2. Stratigraphical, including all cases where there is an actual local disappearance of the reservoir bed from the geological column either against an unconformity or otherwise
3. Lithological, including all cases where a variation in the physical or chemical properties of a particular bed renders it locally permeable

No doubt many objections can be raised against this scheme, but it does attempt to restrict the use of the term "stratigraphic" to those cases where, by definition, it should be applied.

[1] Manuscript received, September 29, 1942.

[2] Geologist, Anglo-American Oil Company Ltd.

[3] W. B. Wilson, "Classification of Oil Reservoirs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 7 (July, 1942), pp. 1291–92.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 2 (FEBRUARY, 1943), PP. 225-228

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

GEOMORPHOLOGY, BY O. D. VON ENGELN

REVIEW BY M. G. CHENEY[1]
Coleman, Texas

Geomorphology, by O. D. von Engeln, professor of geology, Cornell University, Ithaca, New York. 655 pp., 372 illus., 7 pls.; 6×9 inches. The Macmillan Company, 60 Fifth Avenue, New York (July, 1942). Price, $4.50.

The author refers to this book as a systematic and regional treatise of the science of geomorphology. It should serve well the needs of the professional geologist and the university student who has had introductory courses in geology. However, anyone who has a thoughtful curiosity as to the origin and terminology of the many varied facial features of the earth will follow with interest the numerous well explained illustrations and the clear concise discussions embodied in the 23 chapters of this book. Drawings, aerial photographs and topographic-contour maps are used to much advantage. A colored map of South America illustrates the "application of geomorphic units classification over the area of a continent." Bibliographies at the end of each chapter list "classical" and "historical" or "recent" (including 1941) treatises, which together with a detailed index and closing bibliography of references cited make this an up-to-date book of reference.

Much attention has been devoted to the literature and geomorphic terms and features of other countries. Thus, this book offers timely aid to the military strategist, professional or otherwise, who may need help in visualizing the ergs, gassi, oghurds, and sifs of northern Africa; or the dolines, jamas, and uvalas of the karst regions of southwestern Europe, to mention only a few of the terms and conditions of terrane with which many readers may be unfamiliar.

Discussion and illustrations of karst topography will be of particular interest to geologists working in the Central Kansas uplift area. Petroleum geologists will in fact find many practical applications for the material which Professor von Engeln has assembled in this book as the result of his 30 years of study and teaching of geomorphology.

The reviewer is reminded both of the oft repeated statement by the master, Robert T. Hill, that geologists should give more study to physiographic features, and recent speeches of the immediate past-president of this Association, Edgar W. Owen, urging greater use of aerial observation, especially when making preliminary structural interpretations of a region.

The author emphasizes that the analysis of local and regional land forms includes only a portion of the complete field of "geomorphology"; hence, chapters devoted to "Relief Features of the First Order" and "Relief of the Ocean Bottom" follow the introductory chapter "Contents and Backgrounds." Thus many fundamental topics of geological interest and philosophy are included. A case in point is the discussion of the negative anomaly strip of the West Indian Island arc with its related orogenic islands, crustal downbuckle (tectogene), and sequence of deposits within the downwarped area (geotectocline). The geologist will of course seek application of these observed phenomena of the present to geologic events and conditions of the past.

Some idea of the author's literary style and treatment of the subject may be gained from the following paragraph from page 17.

[1] President, Anzac Oil Corporation. Manuscript received, December 28, 1942.

Relief features of the first order seem to have a considerable degree of permanence. They constitute, as it were, the theaters in which geologic dramas are enacted. Stages, which in theaters are frequently altered and rebuilt to fit the succession of productions, may be figuratively compared with the plains, plateaus, and mountains of the second order of relief, and stage scenery, which may be many times shifted during the progress of a single play, matches the items of the third order of relief.

In Chapter IV geomorphic units are defined and classified. Succeeding chapters discuss such topics as "Process, Stage and the Geomorphic Cycle," "The Peneplain Concept," "The Walther Penck Geomorphic System," "Coral Shore Lines, Coral Reefs, and Atolls."

The influence of folding on geomorphic forms is developed especially in chapters on "The Fluvial Geomorphic Cycle in Dome and Fold Structures," "History of the Folded Appalachians," "Fault-Block Mountains and Topography Resulting from Faulting."

The author seems to be on firm ground when he states that "geomorphology is the geologic present which must be mastered before the geologic past can be understood."

RECENT PUBLICATIONS

CALIFORNIA

*"Estimate of the Natural Gas Reserves of the State of California as of January 1, 1941, and as of January 1, 1942," prepared by John F. Dodge *et al. Railroad Commission of California and Dept. Nat. Resources Div. of Oil and Gas Case 4591, Spec. Study S-334* (5th Floor, California State Building, San Francisco, November 15, 1942). 29 pp., 1 map showing principal gas and oil fields. 8.5×11 inches.

*"Wilmington Oil Field," by Walter J. Crown. *California Oil Fields*, Vol. 26, July, 1940, June, 1941 (San Francisco, 1942), pp. 5–11; 5 figs.

*"Edison Oil Field," by Fred E. Kasline. *Ibid.*, pp. 12–18; 4 pls.

*"Webster Area of Midway-Sunset Oil Field," by R. N. Ayars. *Ibid.*, pp. 19–24; 4 pls.

*"The Outlook for New Fields in California and a Review of Recent Discoveries," by George R. Kribbs. *Petrol. World*, Vol. 39, No. 12 (Los Angeles, December, 1942), pp. 18–26; 1 map, 2 charts.

*"Geology of Northwest Wilmington and Torrance Fields, California," by W. R. Cabeen and A. L. Hunter. *Oil and Gas Jour.*, Vol. 41, No. 36 (January 14, 1943), pp. 70–74; 3 figs.

GENERAL

Landscape (As Developed by the Processes of Normal Erosion), by C. A. Cotton. The author is professor of geology in Victoria University College, Wellington, New Zealand. The book is an exposition of the elementary principles of geomorphology. 301 pp., 214 text figs., 44 pls. of photographs. 5.75×8.75 inches outside dimensions. Cloth. Cambridge University Press Department, The Macmillan Company, 60 Fifth Avenue, New York. Published, May, 1942. Price, $4.75.

*"Graphical and Mechanical Determination of the True Dip from Magnetically Orientable Cores Taken in Crooked Holes," by G. D. Hobson. *Jour. Inst. Petroleum*, Vol. 28, No. 227 (South Kensington, London, November, 1942), pp. 274–80; 2 figs.

Economic Mineral Deposits, by Alan M. Bateman. 898 pp., 201 figs., 26 tables, many selected references, 28-page index. Chapt. 16, "The Mineral Fuels," contains a section on "Petroleum and Associated Products" (pp. 643–83; 22 figs.). The book is divided into three parts: (I) General Principles and Processes, (II) Ore Deposits, and (III) Nonmetallic Minerals. John Wiley and Sons, Inc., New York (1942). Price, $6.50.

*"Foraminiferal Homonyms," by Hans E. Thalmann. *Amer. Midland Naturalist*, Vol. 28, No. 2 (Notre Dame, Indiana, September, 1942), pp. 457–62.

*"Nomina Bradyana Mutata," *ibid.*, pp. 463–64.

*"Foraminiferal Genus Hantkenina and Its Subgenera," by Hans E. Thalmann. *Amer. Jour. Sci.*, Vol. 240 (New Haven, November, 1942), pp. 809–20; 1 pl., 2 tables.

*"Electrical Logging to Determine Character of Formations," by Lester C. Uren. *Petrol. Engineer*, Vol. 14, No. 3 (Dallas, Texas, December, 1942), pp. 46–56; 1 fig.

*"Unsatisfactory Exploration Status Demands Attention," by E. DeGolyer. *Oil Weekly*, Vol. 108, No. 4 (Houston, Texas, December 28, 1942), pp. 15–16. Address delivered before quarterly meeting of Interstate Oil Compact Commission, December 19, 1942, at Oklahoma City.

*"Correlation of the Devonian Sedimentary Formations of North America," by G. Arthur Cooper, chairman, *et al. Bull. Geol. Soc. America*, Vol. 53, No. 12, Pt. 1 (New York, December 1, 1942), pp. 729–94; 1 pl., 1 fig. Contains 4th chart of series prepared by committee on stratigraphy of National Research Council, Carl O. Dunbar, chairman.

*"Abstracts of the Geological Society of America, December Meeting at Ottawa (Canceled)." *Ibid.*, Pt. 2, pp. 1795–1814.

**Ibid.*, "Cordilleran Section Meeting at California Institute of Technology in April," pp. 1815–26.

*"Abstracts of the Paleontological Society, December Meeting at Ottawa (Canceled)." *Ibid.*, pp. 1827–34.

**Ibid.*, "Pacific Coast Branch Meeting at California Institute of Technology in April," pp. 1835–40.

*"Abstracts of Society of Vertebrate Paleontology, December Meeting at Ottawa (Canceled)." *Ibid.*, pp. 1841–44.

*"Abstracts of Section E, American Association for the Advancement of Science, December Meeting at New York (Canceled). *Ibid.*, pp. 1845–52.

*"Directional Redrilling of Piercement Type Dome to Increase Recovery," by J. Zaba. *Oil and Gas Jour.*, Vol. 41, No. 36 (January 14, 1943), pp. 31–33; 3 figs.

OKLAHOMA

*"A Bibliography of Oklahoma Oil and Gas Pools," compiled by Alan G. Skelton and Martha B. Skelton. *Oklahoma Geol. Survey Bull. 63* (Norman, 1942). 230 pp.

PENNSYLVANIA

*"Electrical Well Logging in the Eastern States," by Parke A. Dickey. *Pennsylvania Topog. and Geol. Survey Prog. Rept. 129* (Harrisburg, December, 1942). 30 pp., 20 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Volume 12, No. 3 (December, 1942).

"The Rate of Deposition of Sediments: A Major Factor Connected with Alteration of Sediments after Deposition," by W. H. Twenhofel.

"Physical and Chemical Changes in Sediments after Deposition," by W. C. Krumbein.

"The Effect of Macro-Organisms upon Near-Shore Marine Sediments," by E. C. Dapples.

"Changes Produced by Microörganisms in Sediments after Deposition," by Claude E. Zobell.

"Memorial to Professor Charles Schuchert," by W. H. Twenhofel.

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 17, No. 1 (January, 1943).

"The Siphuncle of Late Paleozoic Ammonoids," by A. K. Miller, A. G. Unklesbay.

"The Discovery of Fossil Vertebrates in North America," by George Gaylord Simpson.

"Strophomenacea of the Cedar Valley Limestone of Iowa," by Merrill A. Stainbrook.

"*Acila princeps*, A New Upper Cretaceous Pelecypod from California," by Hubert G. Schenck.

"Marine Invertebrate Faunas of the Buried Beaches near Nome, Alaska," by F. Stearns MacNeil, John B. Mertie, Jr., and Henry A. Pilsbry.

"A Restudy of the Foraminiferal Genera *Pseudorbitoides* and *Vaughanina*," by Thomas Wayland Vaughan and W. Storrs Cole.

"New Lower Ordovician Trilobites from Levis, Quebec," by Franco Rasetti.

"Some Unusual Cystoids and Crinoids from the Niagaran (Silurian) of West-Central Ohio," by Daniel A. Busch.

"Pleistocene Horse Teeth from Saskatchewan," by Loris S. Russell.

"Lower Tertiary *Aturia* from Palestine," by Moshe Avnimelech.

"Pleistocene Mollusks from Margarita Island, Venezuela," by Horace G. Richards.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGIST
VOL. 27, NO. 2 (FEBRUARY, 1943), PP. 229-237, 1 FIG.

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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(*Continued on page* 232)

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Hurry, Phil	1119 N. W. Thirty-seventh St., Oklahoma City, Okla.	Lt.	U. S. Navy
Kinser, James H.	Box 1059, Eustis, Fla.	Lt.	U. S. Navy
Lindsay, Sidney Afton	957 Eng. Topo. Co. (Avn.), Army Air Base, Colorado Springs, Colo.		Army Air Corps
Lott, Frederick S.	Naval Ordnance Lab., Washington, D. C.	Lt. Com.	U. S. Navy
Maravich, Milan D.	615 N. Kickapoo, Shawnee, Okla.		U. S. Army
McNutt, G. R.	1501 Oneal St., Greenville, Tex.	Lt.	Army Air Corps
Myers, Clay Kenton	99 Hawthorne Ave., Albany, N. Y.		U. S. Navy
Nelson, Jean O.	2101 W. Summit, San Antonio, Tex.		Corps of Engineers
Parker, Norbert A.	R.R. 2, Fort Wayne, Ind.		Merchant Marines
Quigley, C. M., Jr.	Maysville, Mo.	Pvt.	Corps of Engineers
Sappington, Chester	3732 Barbara Lane, Houston, Tex.	Lt.	U. S. Navy
Simon, Louis J., Jr.	317 Pasqual Ave., San Gabriel, Calif.	Lt.	U. S. Army
Stoker, Carl E.	Carter Oil Co., Box 801, Tulsa, Okla.		U. S. Navy
Thorup, Richard Russell	133 Willow St., Salinas, Calif.		U. S. Navy
Tollefson, E. H.	332 Buckhannon Ave., Clarksburg, W. Va.	Lt.	U. S. Navy
Tucker, Reagan	521 Naples St., Corpus Christi, Tex.		U. S. Army
Turner, Johnathan D.	Local Defense School, Treasure Island, San Francisco, Calif.	Ens.	U. S. Navy
Van Eaton, Raymond A.	Mills-Bennett Prod. Co., 3402 Gulf Bldg., Houston, Tex.	Lt.	U. S. Army
Verckler, Stewart P.	Box 532, Abilene, Kan.		U. S. Army
Wails, Elmer D.	Midstates Oil Corp., 518 Natl. Bank of Tulsa Bldg., Tulsa, Okla.	Pvt.	Corps of Engineers
Ward, Roland V.	407 E. High St., Charlottesville, Va.		U. S. Navy
Woodward, Albert F.	3928 Stockbridge, Los Angeles, Calif.	Lt.	Corps of Engineers

JOINT ANNUAL MEETING, FORT WORTH, APRIL 7–9, 1943

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
SOCIETY OF EXPLORATION GEOPHYSICISTS

F. L. AURIN[1]
Fort Worth, Texas.

OFFICERS AND COMMITTEE CHAIRMEN

A.A.P.G.

President, F. L. Aurin, Fort Worth, Texas
Past-President, Edgar W. Owen, San Antonio, Texas
Vice-President, Paul Weaver, Houston, Texas
Secretary-Treasurer, E. O. Markham, Tulsa, Oklahoma
Editor, W. A. Ver Wiebe, Wichita, Kansas

[1] President of the Association.

S.E.P.M.

Pres., H. L. Driver, Los Angeles, Calif.
Past-Pres., H. V. Howe, Baton Rouge, La.
Past-Pres., Carey Croneis, Chicago, Ill.
Vice-Pres., Parker D. Trask, Washington, D. C.
Secy.-Treas., H. B. Stenzel, Fort Worth, Tex.
Editor, J. Marvin Weller, Urbana, Ill.
Editor, W. H. Twenhofel, Madison, Wis.

S.E.G.

Pres., Frank Goldstone, Houston, Tex.
Past-Pres., H. B. Peacock, Houston, Tex.
Vice-Pres., R. D. Wyckoff, Pittsburgh, Pa.
Secy.-Treas., T. I. Harkins, Houston, Tex.
Editor, J. A. Sharpe, Tulsa, Okla.
Bus. Mgr., J. F. Gallie, Washington, D. C.

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Pres., Karl A. Mygdal, Pure Oil Company, Box 2107, Fort Worth, Texas
Past-Pres., J. B. Lovejoy, Gulf Oil Corporation, Box 1290, Fort Worth, Texas
Vice-Pres., William J. Hilseweck, Gulf Oil Corporation, Fort Worth, Texas
Secy.-Treas., Richard H. Schweers, The Texas Company, Box 1720, Fort Worth, Texas

FORT WORTH ANNUAL MEETING CHAIRMEN

General	Karl A. Mygdal, Pure Oil Company, Box 2107
Technical program	A. I. Levorsen, 221 Woodward Boulevard, Tulsa, Okla.
Technical arrangements	Thomas B. Romine, Sinclair Prairie Oil Co., Box 1990
Hotels	Ralph H. Cummins, Cummins and Berger, 1601–03 Trinity Bldg.
Finance	Richard H. Schweers, The Texas Company, Box 1720
Reception	J. B. Lovejoy, Gulf Oil Corporation, Box 1290
Registration	William J. Nolte, Stanolind Oil and Gas Company
Educational exhibits	Herbert H. Bradfield, The Texas Company, Box 1720
Entertainment	David Donoghue, Fort Worth National Bank Bldg.
Publicity	John S. Sparks, Fort Worth *Star-Telegram*
S.E.P.M.	Gayle Scott, Texas Christian University
S.E.G.	John H. Wilson, Independent Exploration Company

ANNOUNCEMENT

The 28th annual meeting of the American Association of Petroleum Geologists, the 17th annual meeting of the Society of Economic Paleontologists and Mineralogists, and the 13th annual meeting of the Society of Exploration Geophysicists will be held on April 7, 8, and 9, 1943, at the Hotel Texas, Fort Worth, Texas, at the invitation of the Fort Worth Geological Society.

WAR-TIME CONFERENCE

The Office of War Information and Office of Defense Transportation have released a recent statement in which the following is quoted. "Responding to requests for the attitude of the Office of Defense Transportation on the holding of conventions involving inter-city travel, Mr. Eastman said in a formal statement that individual associations must make their own decisions. He indicated, however, that no such gatherings would be justified, in view of war burdens on the transportation systems, unless they would help to shorten the War."

The petroleum requirements for civilian needs, war industries, and Armed Forces are of unquestioned paramount importance in our War program and since the Office of Petroleum Administration for War, and others, have recognized that ample supplies of petroleum and its products are positively necessary for the successful prosecution of the war, and, further, that the replacement of these declining reserves must be maintained by the discovery of new reserves (which at the present time are rather critical), then it is up to the petroleum industry to safeguard these vital requirements by not only the development of present known reserves, but also the diligent and intensified search for new reserves. The petroleum geologists and geophysicists have one of the most important parts to take in this program. With this in mind, the executive committee has decided that the program of our meeting would be mostly restricted to subjects, discussions, and symposiums on the important work that the petroleum geologists and geophysicists can do to assist in carrying out this program to a successful conclusion. So many petroleum geologists and geophysi-

CHAIRMAN OF A.A.P.G. CONVENTION COMMITTEES

Seated, right to left: David Donoghue, entertainment; Karl A. Mygdal, Pure Oil Company, general chairman and president of Fort Worth Geological Society; J. B. Lovejoy, Gulf Oil Corporation, reception; Wm. J. Nolte, Stanolind Oil and Gas Company, registration.

Standing, left to right: Thos. B. Romine, Sinclair Prairie Oil Company, arrangements; John S. Sparks, Jr., publicity; Richard H. Schweers, The Texas Company, finance; Ralph H. Cummins, hotels; H. H. Bradfield, The Texas Company, educational exhibits.

Committee chairmen not shown in photograph: A. I. Levorsen, technical program; Gayle Scott, S.E.P.M. representative; John H. Wilson, S.E.G. representative.

cists have gone into both the Armed Forces and civilian capacities directly connected with the War Effort, that many exploration companies may be handicapped, or at a disadvantage, in their efforts for the discovery of new fields, so that with our limited personnel it is evident that the coöperation of everybody, the exchange of information, and the presentation and discussion of important subjects will be of much assistance to all concerned.

The time for the meeting has been reduced to one day of business meetings and committee conferences and two days of technical sessions. The technical sessions of each forenoon are to continue until 12:30 P.M., in order to avoid too much congestion at the noon meal hour. College groups expecting to hold luncheons should make plans early and arrange with hotels for space in advance.

WAR RESERVES AND DISCOVERIES

Chairman Levorsen, of the technical program, announces that the sessions are to be devoted to War Reserves and Discoveries, and it is planned to eliminate papers of only local interest, except for presentation by title and abstract in the printed program, for subsequent publication in full in the *Bulletin*. Authors are requested to send abstracts to Association Headquarters, Box 979, Tulsa, Oklahoma, by March 1. It may be that opportunity will be offered to deliver a few miscellaneous papers orally at the meeting.

No formal entertainment, no banquet, no dance, no golf tournament, no field trips are planned.

OUTLINE OF PROGRAM

Each day's sessions are outlined as follows.

Wednesday A.M., April 7
- Annual business committee
- Business meetings of standing and special committees

Wednesday P.M.
- Various research committee conferences

Wednesday Night
- Research committee: "Discovery Thinking"

Thursday A.M., April 8
- Nomination of officers
- Presidential addresses
- War and Personnel Problems
- Reviews of Wildcatting and Geologic Progress

Thursday P.M.
- Major addresses by leaders in the oil industry

Thursday Night
- Special address and smoker

Friday A.M., April 9
- Symposium on Secondary Recovery and Stripper Wells

Friday P.M.
- Symposium to focus attention of oil industry on Most Favorable Areas for Wildcatting for War Needs
- Annual business meeting

EXHIBITS

Exhibits of exploratory equipment and methods, both field and office, are being planned. Previous oil-field equipment exhibitors, map makers, and others have expressed their desire for space. Reservations for display space should be directed to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma.

Strictly educational and scientific exhibits will be displayed as usual. State geological surveys, educational institutions, and geological societies are invited to set up exhibits under supervision and responsibility of their own representatives. Map panels and display tables of limited space will be provided for such exhibits. Requests for space should be sent to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma.

HOTELS

Fort Worth is like every other city in the country in that hotel accommodations are generally taxed to near capacity. With this in mind you are urged to do the following.

1.—Hotel reservations should be made *early* by each person directly with the hotel of his choice. Request the hotel for confirmation. The hotel committee, with Ralph H. Cummins, chairman, 1603 Trinity Building, Fort Worth, Texas, will be glad to give advice about hotel accommodations. Members who find they can not attend should promptly cancel any reservations they have made.

2.—It may be necessary to double up in some cases in order to accommodate everyone. Plan to do this if possible.

3.—On account of the transportation and limited hotel accommodations, you are urgently requested to discourage the bringing of non-member guests and wives to the meeting.

Hotel Texas (Headquarters)	
Single	$ 2.25 up
Double	3.50 up
Twin beds	4.00 up
Suites	10.50 up

Worth Hotel ($3\frac{1}{2}$ blocks from headquarters)	
Single	$ 2.75 up
Double	4.00 up
Twin beds	4.50 up
Suites	12.00 up

Westbrook Hotel (3 blocks from headquarters)	
Single	$ 2.25 up
Double	3.00 up
Twin beds	4.00 up
Suites	6.00 up

Blackstone Hotel (3 blocks from headquarters)	
Single	$ 3.50 up
Double	5.00 up
Suites	16.00 up

Commercial ($3\frac{1}{2}$ blocks), Single, $2.00, Double, $4.00; Hickman (7 blocks); Milner (opp. Hdqtrs.)

Tourist Courts

El Patio Lodge, 1815 E. Lancaster, US 80 E.
Mayo Courts, 1917 E. Lancaster, US 80 E.
Rockway Court, 5900 Camp Bowie, US 80 W.
Motor Inn Hotel, 5225 Camp Bowie, US 80 W.
Ft. Worth Tourist Lodge, 5821 Camp Bowie, US 80 W.
Shady Tour-Rest, 4036 E. Belknap, US 377 N.
Casa Loma, Jacksboro Highway, Texas 199 NW.
Rockwood Court, Jacksboro Highway, Texas 199 NW.

OPEN LETTER TO THE GEOLOGICAL DEPARTMENTS IN PETROLEUM INDUSTRY[1]

F. L. AURIN[2]
Fort Worth, Texas

Since the geological departments of the oil companies have lost a large part of their personnel through the draft and volunteering for service in the Armed Forces, thereby creating a shortage of manpower in these departments, and since there is unanimous opinion by the governmental agencies and others that it is vital that extensive exploration work be increased for the development of known reserves and especially for the discovery of new reserves, it is the desire of the American Association of Petroleum Geologists to assist in replacing the required personnel, even though it may be only for the duration of the present emergency.

With this in mind, we are suggesting to you that, if you need additional assistants, we may help you find them. As you know, the Headquarters office maintains a file on geologists seeking employment. We also have a file of questionnaires showing their training and experience. The number of unemployed is limited. Many of these men and women are above draft age, or have been deferred from, or have not qualified for, military service because of dependents, physical disqualifications, or other reasons. Many of them have had broad experience in all phases of petroleum geology. Inquiries have also been received from well experienced petroleum geologists now in the Armed Forces, who are above the present age limit for service, whose present work would not be considered as essential from a military standpoint. These men are anxious to return to petroleum work and make a greater contribution to the War Effort; however, in order to make such arrangements it is necessary to have definite commitments for employment in a defense industry in order to return to civilian employment.

Our object in bringing this to your attention is not only to help the individual, even though all of them may not be members of the A.A.P.G., but also to further the War Effort by contributing the complete efforts of all the petroleum geologists to the necessary and important task—"The Discovery of New Petroleum Reserves."

Please give this matter serious consideration and do not hesitate to ask our coöperation.

[1] Manuscript received, January 23, 1943.

[2] President of the Association.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 2 (FEBRUARY, 1943), PP. 238-240, 1 FIG.

Memorial

TRACY GILLETTE

(1905–1942)

Tracy Gillette was born, September 24, 1905, in the town of Huron, Wayne County, New York. He died, November 9, 1942, at Urbana, Illinois. His parents were Enos E. Gillette and Phoebe Tracy Gillette. From the age of 2 he lived with his grandparents, Roswell S. Tracy and Jane McLaughlin Tracy. Between the ages of 7 to 16, he attended the North Rose Union School and North Rose High School, completing one year of high

school. During the next 2 years he worked on his father's muck and fruit farm. He then returned to high school and graduated in 1926. After working again for 2 years, in the fall of 1928, he entered the University of Rochester and graduated with an A.B. degree in 1932. In 1931 he married Ruth Schneeberger of Irondequoit, New York. From 1932 to 1934 he held a graduate assistantship at the University of Rochester and in 1934 received the M.S. degree. In the fall of 1934 he entered The Johns Hopkins University and received the Ph.D. degree in 1937. His dissertation was on "The Clinton of New York State from Rochester to Clinton." The preliminary work on which this stratigraphic study was based was used as his master's thesis and was published in 1940 as *New York State Museum Bulletin 320*, entitled "Geology of the Clyde and Sodus Bay Quadrangles, New York." A more comprehensive stratigraphic report on "Geology of the Clinton of New York State" is being published by the New York State Museum. He also prepared the section on the Silurian of Central and Central Western New York for the Geological Society of America's correlation charts and handbook. Jointly with Mr. Hartnagel he prepared a report for the New York State Museum on the "Trenton Gas Fields of New York." In this work he visited practically all the old Trenton gas fields and assembled a wealth of material concerning them.

He was a temporary member of the New York State Museum from 1932 to 1939, engaged in areal mapping and stratigraphic study of the Clinton formation and collection of the data on the gas fields of New York. During the years 1932 to 1935, he was engaged in consulting work in the Geneva, Baldwinsville, Clyde, Weedsport, Auburn, and Bristol gas fields of New York. In 1933, he was employed as a consultant for oil and gas prospecting in Brewster and Pecos counties, Texas, and in 1936 in Lewis County, Kentucky.

In October, 1936, he joined the geologic staff of the Consolidated Oil Company in New York as assistant to the chief geologist and as chief geologist of the subsidiary Venezuelan Petroleum Company. In 1939 he spent 2 months in geologic work in Venezuela for the Venezuelan Petroleum Company. It was in Venezuela that he contracted the obscure disease that caused his death. In March, 1941, he was appointed assistant geologist on the Illinois Geological Survey and in 1942 was promoted to associate geologist, which position he held at the time of his death. He had practically completed a report on the subsurface stratigraphy of the Kinderhook-New Albany strata in Illinois.

He became a member of the American Association of Petroleum Geologists in 1937. He was elected to membership in Phi Beta Kappa and Sigma Xi, and was an associate member of the American Institute of Mining and Metallurgical Engineers.

During the brief span of his career, Tracy Gillette became known to the geologists of two universities and two State geological surveys, and to many persons in the oil and gas industry, both geologists and business men. By all he was held in the highest esteem. Inherent character and seriousness of purpose directed him throughout life. The discipline of being early thrown on his own resources developed and matured these qualities. Behind this steadfastness was a modest bearing and a kindly and generous personality. He laid claim only to that which he achieved for himself, and was unusually appreciative of such kindness and friendship as his own unselfishness deservedly won him. Having financed his education through his own efforts, he had a full realization of its value; and he was recognized at both the University of Rochester and at The Johns Hopkins University as an outstanding student both in his tireless application to his work and in his mature grasp of its import. This same perseverence and complete reliability characterized his work in the subsequent application of his training in his service to his various employers. To him the greatest joy in life was to do a difficult job well. This quality gave him the power to overcome all obstacles and to carry through to a successful conclusion whatever he undertook. The practical necessities of life, however, never impaired a truly scholarly approach to his problems or blunted his sympathetic understanding, earnest helpfulness, and warm

friendship for others. He worked hard and sacrificed much to prepare himself for his geological career, hard work and sacrifice that were cheerfully shared by a devoted and equally unselfish wife. Cruel fate has deprived them of sharing together the achievement and enjoyment of the fruits of their years of preparation. The science and the profession have lost one of the most promising of their younger men.

JOSEPH T. SINGEWALD, JR.

THE JOHNS HOPKINS UNIVERSITY
BALTIMORE, MARYLAND
December 30, 1942

DONALD ALEXANDER FULLERTON

(1909–1942)

Word has been received of the death of Captain Donald A. Fullerton, an associate member of the Association. Captain Fullerton was born in Grand Pré, Nova Scotia, October 12, 1909. His parents, Oliver Fullerton and Jettie Maude Fullerton (née Kilcup), moved to the United States in 1924, and Donald graduated from the Mission, San Francisco, California, High School with high honors and as a "major" in the Reserve Officers Training Corps. After 2 years at the New Mexico School of Mines at Socorro, he entered the University of Washington, Seattle, in September, 1935, and graduated wit the B.Sc. degree in geology in 1938. He was a Graduate Teaching Fellow while pursuing graduate studies at Stanford University during 1938. In November, 1938, Fullerton joined the Standard Oil Company of California, at San Francisco, as assistant geologist, and in December went to India for the Indian Oil Concessions, Ltd. He was elected an associate member of the Association in 1939.

Fullerton's professional career as geologist for the Indian Oil Concessions, Ltd., was terminated by his enlistment in the Duke of Wellington's regiment in January, 1940. He was immediately assigned to the Officers Training Corps and had advanced to captaincy at the time of his death. Captain Fullerton was drowned when his boat capsized while he was engaged in military exercises around Karachi, India. No details are available about the circumstances of his death.

Captain Fullerton was married to Miss Mary Draper, of Edinburgh, and of Karachi, India, just before entering military service. He is survived by his wife and infant daughter, and his parents, all of whom reside at 304 Mill Street, Ukiah, California.

Captain Fullerton's friends will be saddened by this news. They knew him as a pleasant companion, as a gentleman of unfailing courtesy, and as a well trained geologist of great promise in his chosen profession.

G. M. CUNNINGHAM

SAN FRANCISCO, CALIFORNIA
January 5, 1943

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 27, NO. 2 (FEBRUARY, 1943) PP. 241-248.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Forth Worth Geological Society has elected officers for 1943: president, KARL A. MYGDAL, Pure Oil Company; vice-president, WILLIAM J. HILSEWECK, Gulf Oil Corporation; secretary-treasurer, RICHARD H. SCHWEERS, The Texas Company, Box 1720. Noon luncheons are held at the Worth Hotel, every Monday. Visiting geologists are welcome.

The Dallas Petroleum Geologists elected new officers for the year, as follows: president, S. A. THOMPSON, Magnolia Petroleum Company, Box 900; vice-president, JOSEPH M. WILSON, Continental Building; secretary-treasurer, ROBERT I. SEALE, Schlumberger Well Surveying Corporation, 1004 Continental Building; member of the executive committee, T. K. KNOX, Republic Natural Gas Company, Houseman Building. Regular luncheon is held on the first Monday of each month, at noon, at the Petroleum Club, Adolphus Hotel.

Officers of the Corpus Christi Geological Society, Corpus Christi, Texas, are: president, W. ARMSTRONG PRICE, consulting geologist, Texas Building, Box 1860; vice-president, L. B. HERRING, consulting geologist, Driscoll Building; secretary-treasurer, HENRY D. McCALLUM, Humble Oil and Refining Company, Box 1271. Regular luncheons are held every Monday in the Petroleum Room, Plaza Hotel, at 12:05 P.M.

GEORGE E. HEAP, formerly in charge of the oil and gas activities for the Indiana Geological Survey, is in the Army Air Corps at Miami Beach, Florida.

P. HASTINGS KELLER, formerly consulting geologist in Detroit, Michigan, has succeeded GEORGE E. HEAP, in charge of the oil and gas section of the Indiana Geological Survey at Indianapolis.

RAYMOND W. SNYDER, of Denver, Colorado, is a captain in the Air Corps, commanding a school squadron at Buckley Field.

W. W. KEELER, geologist with the Skelly Oil Company, Tulsa, Oklahoma, died from a sudden heart attack, in Topeka, Kansas, January 3.

GILBERT P. MOORE is manager of the operating headquarters of the oil division of the Auto-Ordnance Corporation at Wichita, Kansas. E. K. EDMISTON is chief geologist and ANTHONY FOLGER is geological consultant.

L. DAVID HAWLEY is an ensign at the U. S. Naval Training School at Tucson, Arizona.

CARROLL E. COOK is at present in Buenos Aires, Argentina, with the Argentina Oil Company. His mailing address remains 506 West 22nd Street, Austin, Texas.

CECIL VERNON HAGEN, a lieutenant in the Naval Reserve was transferred to the Naval Air Training Station, Corpus Christi, Texas, for a flying instructor's course.

FRED W. BATES, independent geologist and paleontologist of Lafayette, Louisiana, has been recently retained in the capacity of consulting geologist for the Gulf coastal area by the Danciger Oil and Refining Company of Fort Worth, Texas.

The death of Captain DONALD ALEXANDER FULLERTON is reported as having occurred in India. Fullerton was previously with the Standard Oil Company of California, at San Francisco.

RAYMOND A. VAN EATON, formerly with the Mills Bennett Producing Company at Houston, Texas, is in foreign service with the U. S. Army.

The officers of the Appalachian Geological Society, Charleston, West Virginia, have been re-elected for 1943: president, CHARLES BREWER, JR., of Godfrey L. Cabot, Inc.; vice-president, H. J. WAGNER, Public Service Commission of West Virginia; vice-president, RALPH N. THOMAS, recently of the Inland Gas Corporation, Ashland, Kentucky, and now in army service; vice-president, JOHN V. GOODMAN, Pittsburgh, Pennsylvania; secretary-treasurer, R. S. HYDE, West Virginia Gas Corporation; and editor, R. C. LAFFERTY, recently of the Owens, Libbey-Owens Gas Department, and now in the navy.

The Society of Economic Paleontologists and Mineralogists has elected the following officers, effective in April, 1943: president, J. HARLAN JOHNSON, Golden, Colorado; vice-president, R. DANA RUSSELL, San Diego, California; secretary-treasurer, H. B. STENZEL (re-elected), Austin, Texas.

EDGAR KRAUS, with the Atlantic Refining Company, has moved from Carlsbad, New Mexico, to Dallas, Texas, where he is regional geologist.

NATHAN C. DAVIES, consulting geologist and engineer, has moved his office from Evansville, Indiana, to 1102 Oakland Avenue, Mt. Vernon, Illinois.

A. L. BOWSHER was given leave of absence from the Kansas State Geological Survey to enter the service. He is with the Corps of Engineers at Fort Leonard Wood, Missouri.

KURT H. DE COUSSER, of Lansing, Michigan, has been elected to serve his second term as president of the Michigan Oil and Gas Association. He is completing his fourth year as a member of the State of Michigan Oil Advisory Board.

A. M. LLOYD, of the Sun Oil Company, Dallas, Texas, spoke on "The Jurassic of Northern Louisiana and Southern Arkansas," at the meeting of the Houston Geological Society, December 17.

Major J. E. EATON, Air Corps, U.S.A., writes from overseas that his address is HQ and HQ Squadron, Twelfth Fighter Command, A.P.O. 525, c/o Postmaster, New York, N. Y.

The 28th annual meeting of the A.A.P.G., together with its associated societies, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists will be held at the Hotel Texas, Fort Worth, Texas, April 7, 8, and 9, 1943.

M. M. KORNFELD has been transferred from Bolling Field, Washington, D. C., to 7th Photographic Intelligence, 28th Air Base Squadron, MacDill Field, Tampa, Florida.

OGDEN S. JONES, geologist in the oil-field section of the Division of Sanitation, Kansas State Board of Health, Lawrence, is the author of two pamphlets: "The State's Responsibility in Oil and Brine Pollution Originating in Oil Fields" (20 pp.) and "A Review of Lease Housekeeping Practices" (15 pp., 7 figs.).

Lieutenant HARRY J. RUSSELL, formerly with Gulf Oil Corporation, Wichita, Kansas, is now serving as an Intelligence Officer in the U. S. Army Air Corps in the A.E.F.

MILTON W. LEWIS has returned from a year's work in the northern part of Mexico,

and is again associated with WALKER S. CLUTE in consulting petroleum geology and valuation engineering. Their business address is Room 211, 811 West 7th Street, Los Angeles, California.

MAURICE SKLAR, seismologist for Shell Oil Company, Inc., has been transferred to the eastern area, with headquarters in Centralia, Illinois. At present he is located at Vandalia, Illinois.

WALTON SUMNER, formerly of the Socony-Vacuum Oil Company, is employed as chemist at the Bureau of Mines experimental station in Longview, Texas.

RICHARD KNAPP PUNCHES, recently with the Phillips Petroleum Company in Amarillo, Texas, has been called to active duty with the Army Engineers.

GEORGES VORBE has discontinued his consulting practice at Midland, Texas, to accept a position as associate professor of geology at the New Mexico School of Mines, Socorro, New Mexico, succeeding M. L. THOMPSON, who is now teaching at the University of Kansas, at Lawrence.

P. E. FITZGERALD, of Dowell Incorporated, Tulsa, spoke before the Tulsa Geological Society, January 12, on "History and Development of Plastics."

L. P. TEAS, consulting geologist, Houston, talked, with motion pictures, on the subject, "South American Observations," before the Houston Geological Society, January 7.

WARD W. WEST, geologist with the Skelly Oil Company, Midland, Texas, has resigned to join the Lario Oil and Gas Company, Wichita, Kansas, which recently opened a district office in Midland.

DANA M. SECOR, geologist for the Skelly Oil Company, Midland, Texas, has resigned to join the Permian basin staff of the Atlantic Refining Company.

JOHN STANLEY ROSS, petroleum engineer with the Federal Power Commission, was killed in Washington, D. C., January 1, in an automobile accident. Ross was formerly with the United States Bureau of Mines and had also worked for a number of oil companies.

DONALD B. WINES, recently with the Central Petroleum Company, Inc., Wichita, Kansas, is division geologist for the Midstates Oil Company, Tulsa, Oklahoma.

HILLARD W. CAREY, geologist with the Halliburton Oil Well Cementing Company, has been elected secretary of the Houston Geological Society, succeeding W. L. HORNER, who has joined the Barnsdall Oil Company, Tulsa, Oklahoma.

Newly elected officers of the West Texas Geological Society, Midland, are: president, FRED H. WILCOX, Magnolia Petroleum Company; vice-president, PRENTISS D. MOORE, Moore Exploration Company; secretary-treasurer, DANA M. SECOR, Atlantic Refining Company.

JAMES H. KINSER entered the Navy last April as a lieutenant and is now serving somewhere in the southwest Pacific.

LEWIS B. KELLUM, professor of geology at the University of Michigan, spoke before the Tulsa Geological Society, January 18, on "Geologic History of North-Central Mexico and Its Bearing on Petroleum Exploration."

At a business meeting of the Shreveport Geological Society, January 4, ROY MORSE, Shell Oil Company, Inc., spoke on "Geological Highlights of Unoccupied China." At a dinner meeting on January 20, WATSON MONROE, U.S.G.S., spoke on "Bauxite."

At the regular monthly meeting, the members of the South Louisiana Geological Society elected the following officers: president, H. E. McGlasson, Stanolind Oil and Gas Company; vice-president, C. B. Roach, Shell Oil Co., Inc.; secretary, A. L. Morrow, Magnolia Petroleum Company; treasurer, D. N. Rockwood, Union Producing Company, all of Lake Charles. Fred W. Bates and J. B. Wharton gave a paper on "Anse La Butte Salt Dome."

Gerard Henny has been appointed a U. S. Customs Guard for the duration and may be addressed in care of Army and Navy Y.M.C.A., 921 South Beacon Street, San Pedro, California.

Francis P. Shepard has resigned his position at Scripps Institution of Oceanography, La Jolla, California, to become associated with the University of California, Division of War Research, at the U. S. Navy Radio and Sound Laboratory, San Diego, California.

Johnathan D. Turner is an ensign at the Local Defense School, Treasure Island, San Francisco, California.

F. A. Afsher resigned his position with Seismograph Service Corporation and is enrolled in the geology department of the University of Chicago, taking post-graduate work leading to a Ph.D. degree.

John C. Dunlap, Old Post Office Building, Chattanooga, Tennessee, is with the U. S. Geological Survey studying minerals in the Appalachian Valley area.

Stuart K. Clark, Continental Oil Company, Ponca City, Oklahoma, spoke before the Tulsa Geological Society, January 4, on "Classification of Faults."

ARMY AIR CORPS COMMISSIONS FOR CIVILIANS WITH DESERT AND TROPIC EXPERIENCE

The Arctic, Desert, and Tropic Information Center of the Army Air Forces has announced that men now in the Army who desire to serve with this organization, and members who are still civilians who have had foreign experience in the desert or tropics and are interested in commissions, should write requesting information from the Director of the Arctic, Desert, and Tropic Information Center, Army Air Forces, Eglin Field, Florida.

GULF FELLOWSHIP IN GEOLOGY

Announcement is made of the establishment by the Gulf Oil Corporation of a Fellowship in Geology at the University of Chicago. First award of this Fellowship will be made for the school year 1943–44 provided qualified candidates are available under war conditions.

The Fellowship stipend will approximate $1200 a year, the Gulf Corporation contributing $900 and the University making available additional funds or allowances equivalent to the tuition requirements, namely $300.

The initial award will be in the field of sedimentation and candidates must have had the equivalent of at least a year of graduate work in geology at an institution of recognized standing. The Fellowship holder will be expected to devote part of his time to research in sedimentation. The Fellowship may be renewed on recommendation of the department. Renewal at the end of 9 months, rather than at the end of a 12-month period is possible if the Fellow works under an accelerated program.

Application forms may be obtained from the Department of Geology, University of Chicago, and must be returned to the University before March 1. The award will be announced April 1.

JOHN M. HILLS, consulting geologist, is president of the Midland Geological Society, Midland, Texas.

FLORENT H. BAILLY, chief geologist of the Pantepec Oil Company of Venezuela, spoke on "Venezuelan Oil Industry in War Time," before the Fort Worth Geological Society, January 18, at a luncheon meeting.

L. W. LEROY, of the Colorado School of Mines, at Golden, spoke at the regular meeting of the Rocky Mountain Association of Petroleum Geologists, at Denver, Colorado, January 18.

CRAMON STANTON, of the United Carbon Company, Charleston, West Virginia, has succeeded R. S. HYDE, of the West Virginia Gas Company, as secretary-treasurer of the Appalachian Geological Society. Hyde is associated with the Petroleum Administrator for War, in Pittsburgh, Pennsylvania.

KILBURN E. ADAMS, formerly geologist for The Texas Company at Tulsa, Oklahoma, has been promoted from night flying instructor to Assistant Flight Commander at the Army's Advanced Glider School under civilian contract at Lamesa Field, Lamesa, Texas.

ELMER W. ELLSWORTH was commissioned a captain in December and is stationed at the Headquarters of the Arctic, Desert and Tropic Information Center, Army Air Force Proving Ground Command, Eglin Field, Florida.

1st Lieutenant LEAVITT CORNING, JR., is with the 12th Air Force somewhere in North Africa. His address is A.P.O. 650, c/o Postmaster, New York City.

Captain EDGAR W. OWEN is somewhere in Australia. His address is A.P.O. 923, c/o Postmaster, San Francisco, California.

Captains L. B. SNIDER and RUAL B. SWIGER are somewhere in the South Pacific.

2nd Lieutenant HOWARD F. COLTON is in the Army Air Corps, stationed at McDill Field, Tampa, Florida.

1st Lieutenant ROBERT H. CUYLER is in the Army Air Corps at Kelly Field, San Antonio, Texas, instructing in map interpretation.

Lieutenant Colonel BYRON RIFE is in the Office of Chief of Ordnance, 3637 Lindell Boulevard, St. Louis, Missouri.

JOHN TRENCHARD is civilian engineer with the Army Engineers at Denison, Texas.

Private C. H. DICKERSON is in the Army Air Corps at Brooks Field, San Antonio, Texas, instructing in aerial map interpretation.

1st Lieutenant FRANK C. ROPER is in the Army Air Corps at Brooks Field, San Antonio, Texas.

Captain J. O. NELSON is in the Army Engineers Corps at Camp Claiborne, Louisiana.

H. L. SCOTT, consulting geologist, has opened an office at 1603 Philtower, Tulsa, Oklahoma.

ANN M. ROBINS is with the General Geophysical Company at Waurika, Oklahoma.

BERNARD N. MOORE is with the Consolidada de Petroleo Maturin, Monagas, Venezuela.

CARROLL H. WEGEMANN, for several years with the Federal Park Service, is connected with the Office of Petroleum Administration for War, at Chicago, Illinois.

TAYLOR COLE, with University Lands, Midland, Texas, is one of ten outstanding young men in Texas in 1942, as announced by the United States Junior Chamber of Commerce.

FRANK SHACKLEFORD BOGGS, JR., geologist with the Shell Oil Company, Inc., Houston, Texas, was killed in an airplane collision last June.

PHIL K. COCHRAN, division geologist for the Carter Oil Company at Shreveport, Louisiana, has been made assistant division superintendent for Carter's southern division.

R. W. BECK, with the Carter Oil Company at Mattoon, Illinois, has been promoted and transferred to Shreveport, Louisiana, as assistant division geologist.

DOROTHY JUNG ECHOLS is no longer associated with The Texas Company and may be addressed at 425 Central Park West, New York City.

New Officers elected for the Illinois Geological Society are: president, DARSIE A. GREEN, Pure Oil Company, Olney; vice-president, J. REX MCGEHEE, Shell Oil Company, Inc., Centralia; secretary-treasurer, FRED H. MOORE, Magnolia Petroleum Company, Mt. Vernon.

MILAN D. MARAVICH has been transferred to a Military Intelligence Training Center at Camp Ritchie, Maryland.

JOHN W. FLUDE is a civilian physicist at the Deperming Station, Naval Supply Depot, Bayonne, New Jersey, employed by the U. S. Navy Bureau of Ordnance.

EMIL OTT is at present engaged in wildcat drilling near Goldthwaite, Texas.

ROBERT P. MCNEAL, formerly of the Seaboard Oil Company in Evansville, Indiana, is with the Shell Oil Company, Inc., at Centralia, Illinois.

It was erroneously stated in the January *Bulletin* that GLEN C. WOOLLEY was the new secretary-treasurer of the Kansas Geological Society. This should have been ROBERT B. MCNEELY, 209 Ellis-Singleton Building, Wichita. Also, since DONALD B. WINES, who was elected vice-president, is now connected with the Midstates Oil Corporation as division geologist at Tulsa, Oklahoma, JACK M. COPASS, Amerada Petroleum Corporation, Wichita, was elected to succeed him.

A. W. WEEKS, of the Office of Petroleum Administration for War, spoke at the February 8 meeting of the Rocky Mountain Association of Petroleum Geologists on "Geology and Oil Development in the Near East."

LORIS J. FULTON, of the Pure Oil Company, has been transferred from Bismarck, North Dakota, to 650 Birch, Denver, Colorado.

E. H. FINCH, of San Antonio, Texas, is newly associated with the Division of Reserves, Office of Petroleum Administrator for War, Washington, D. C.

W. H. GEIS, formerly with the Union Oil Company of California, Los Angeles, may be addressed at 1111 Munsey Building, Washington, D. C.

HOWARD E. ROTHROCK is in the field for the duration of the war, employed by the U. S. Geological Survey, at present in Silver City, New Mexico. He was formerly connected with the National Park Service in Washington, D. C.

PAUL E. FITZGERALD, geologist with Dowell, Inc., Tulsa, is president of the Tulsa, Oklahoma, chapter of Nomads.

HENRY HOWE ROBBINS SHARKEY, formerly geologist with the Continental Oil Company at Lafayette, Louisiana, is now research assistant to W. TAYLOR THOM, JR., professor of structural geology at Princeton University, Princeton, New Jersey.

H. K. SHEARER has resigned from the Hunter Company, Shreveport, Louisiana, to accept an appointment as senior geologist with the U. S. Board of Economic Warfare, for work on war minerals in Brazil.

PROGRESS REPORT OF DISTINGUISHED LECTURE COMMITTEE

John L. Ferguson, chairman of the distinguished lecture committee of the A.A.P.G., reports as follows. In January and February, the affiliated societies of the Association, through the distinguished lecture committee, invited two outstanding research geologists to discuss their work before local geological societies.

Lewis B. Kellum, professor of geology and director of the Museum of Paleontology at the University of Michigan, presented the results of 12 years of research in the structure and stratigraphy of a little-known province when he discussed "The Geologic History of North-Central Mexico and Its Bearing on Petroleum Exploration" before the following societies.

Jan.	*Society*	*Jan.*	*Society*
15	Illinois at Centralia	26	Pacific Section, Los Angeles
16	Ind.-Kentucky, Evansville	30	Corpus Christi
18	Tulsa	*Feb.*	
19	Kansas at Wichita	1	South Texas, San Antonio
20	Okla. City and Shawnee	2	Houston
	at Oklahoma City	2	Shreveport
21	Dallas	3	East Texas at Tyler
22	Fort Worth	4	New Orleans
23	West Texas at Midland	5	Mississippi at Jackson

Ernst Cloos, professor of geology at The Johns Hopkins University, discussed his research in the effect of structural movements on rock constituents in a lecture entitled "Method of Measuring Distortion of Primary Stratigraphic Thickness Due to Flowage and Folding" before these societies.

Feb.	*Society*	*Feb.*	*Society*
1	Tulsa, and A.A.P.G.	4	Oklahoma City
	members at Bartlesville	5	Fort Worth
1	Tulsa	6	Ardmore
2	Kansas at Wichita	8	Illinois at Olney
3	Shawnee		

MEETINGS AND RATIONING

Lee C. Lamar, president of the Michigan Geological Society submits the following. At the first fall meeting of the Michigan Geological Society a discussion was held about holding additional meetings during the year since the rubber shortage and gasoline rationing has become a serious matter. The majority of the members felt it inadvisable to disband the organization and favored a compromise. The executive board considered the plan of having only one meeting every other month during the season or of having dual meetings every other month. The Michigan Geological Society is a statewide organization and meetings have been rotated in the past between four reasonably centrally located towns. This entailed considerable traveling for the members. As an experiment, it was decided to try a program with one paper at 3:00 P.M., dinner at 6:30 and an additional meeting after dinner at 8:00 P.M. The meeting was arranged to coincide with a State oil and gas lease sale which is attended by geologists. Thus, a separate trip was saved for many members of the society. At this meeting, on January 27, the members were unanimous in approving the arrangement. Consequently, it is believed that it will be followed for the duration of the war.

PAST AND PRESENT OFFICERS OF THE ASSOCIATION

Elected In	*At*	*President*	*Vice-President*[1]	*Secretary-Treasurer*[2]	*Editor*[3]
1917	Tulsa	J. Elmer Thomas	Alex Deussen	M. G. Mehl	C. H. Taylor
1918	Oklahoma City	Alex. Deussen	I. C. White[4]	W. E. Wrather	C. H. Taylor
1919	Dallas	I. C. White[4]	Irving Perrine	C. E. Decker	C. H. Taylor
1920	Dallas	W. E. Pratt	Alex. W. McCoy	C. E. Decker	R. C. Moore
1921	Tulsa	G. C. Matson[5]	G. C. Gester	C. E. Decker	R. C. Moore
1922	Oklahoma City	W. E. Wrather	Max W. Ball	C. E. Decker	R. C. Moore
1923	Shreveport	Max W. Ball	F. W. DeWolf	C. E. Decker	R. C. Moore
1924	Houston	J. H. Gardner	E. G. Gaylord	C. E. Decker	R. C. Moore
1925	Wichita	E. L. DeGolyer	R. S. McFarland	C. E. Decker	R. C. Moore
1926	Dallas	Alex. W. McCoy	C. R. McCollom	Fritz L. Aurin	J. L. Rich
1927	Tulsa	G. C. Gester	Luther H. White	David Donoghue	J. L. Rich
1928	San Francisco	R. S. McFarland	J. E. Elliott	David Donoghue	J. L. Rich
1929	Fort Worth	J. Y. Snyder[6]	Fred H. Kay	A. R. Denison	F. H. Lahee
1930	New Orleans	Sidney Powers[7]	Ralph D. Reed[8]	Marvin Lee	F. H. Lahee
1931	San Antonio	L. P. Garrett	L. C. Decius	Frank R. Clark	F. H. Lahee
1932	Oklahoma City	F. H. Lahee	R. J. Riggs	W. B. Heroy	R. D. Reed[8]
1933	Houston	Frank R. Clark	George Sawtelle	W. B. Heroy	L. C. Snider
1934	Dallas	W. B. Heroy	E. B. Hopkins[10]	M. G. Cheney	L. C. Snider
1935	Wichita	A. I. Levorsen	F. A. Morgan	E. C. Moncrief	L. C. Snider
1936	Tulsa	Ralph D. Reed[8]	C. E. Dobbin	Chas. H. Row	L. C. Snider
1937	Los Angeles	H. B. Fuqua	C. L. Moody	Ira H. Cram	W. A. Ver Wiebe
1938	New Orleans	D. C. Barton[9]	H. W. Hoots	Ira H. Cram	W. A. Ver Wiebe
1939	Oklahoma City	Henry A. Ley	L. M. Neumann	Ed. W. Owen	W. A. Ver Wiebe
1940	Chicago	L. C. Snider	John M. Vetter	Ed. W. Owen	W. A. Ver Wiebe
1941	Houston	Ed. W. Owen	Earl B. Noble	E. O. Markham	W. A. Ver Wiebe
1942	Denver	F. L. Aurin	Paul Weaver	E. O. Markham	W. A. Ver Wiebe

[1] From March, 1929, to March, 1932, the corresponding office was *first vice-president*
[2] From March, 1929, to March, 1932, the corresponding office was *second vice-president in charge of finances.*
[3] From March, 1929, to March, 1932, the corresponding office was *third vice-president in charge of editorial work.*
[4] Died, November 25, 1927.
[5] Died, January 3, 1940.
[6] Died January 10, 1939.
[7] Died, November 5, 1932.
[8] Died, January 29, 1940.
[9] Died, July 8, 1939.
[10] Died, July 5, 1940.

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U. S. Geological Survey
2nd Vice-President - - - - - John E. Blixt
The Texas Company
Secretary-Treasurer - - - - Robert E. Spratt
U. S. Geological Survey, 208 Custom House

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Cosmopolitan Hotel.

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President - - - - - - - - Darsie A. Green
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Vice-President - - - - - - J. Rex McGehee
Shell Oil Co., Inc., Box 476, Centralia

Secretary-Treasurer - - - - - Fred H. Moore
Magnolia Petroleum Corp., Box 535, Mt. Vernon

Meetings will be announced.

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INDIANA-KENTUCKY GEOLOGICAL SOCIETY
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Carter Oil Company

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Phillips Petroleum Company

Secretary-Treasurer - - - - Robert F. Eberle
The Superior Oil Company

Meetings will be announced.

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WICHITA, KANSAS

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Vice-President - - - - - - Jack M. Copass
Amerada Petroleum Corp., Box 995
Secretary-Treasurer - - - Robert B. McNeely
209 Ellis-Singleton Building
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

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Ohio Oil Company

Secretary-Treasurer - - - - - T. H. Philpott
Carter Oil Company, Drawer 1739

Meets the first Monday of every month, October to May, inclusive, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

LOUISIANA

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Magnolia Petroleum Company
Treasurer - - - - - - - - - D. N. Rockwood
Union Producing Company

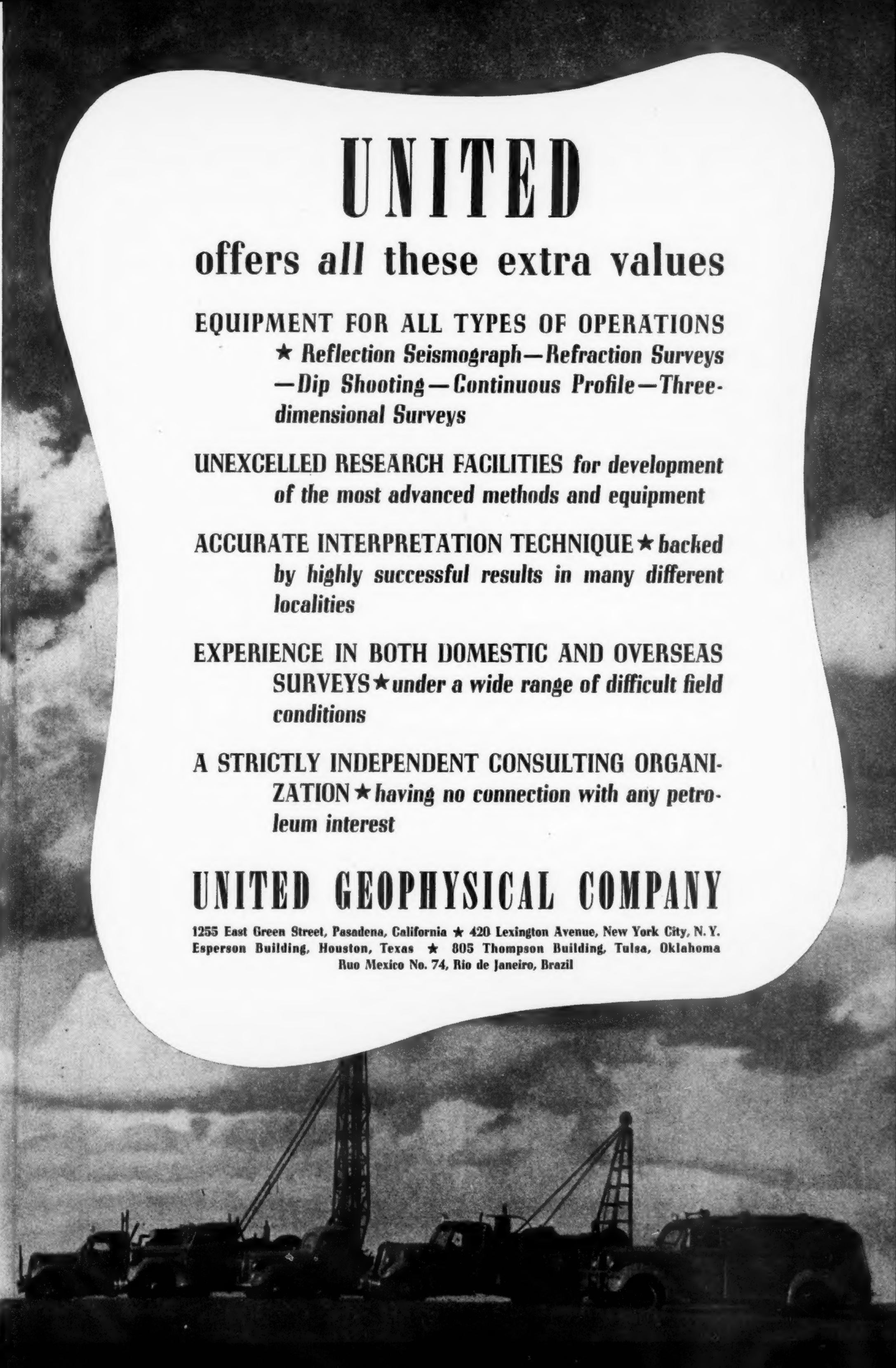
Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - Lee C. Lamar
Carter Oil Company, Mt. Pleasant
Vice-President - - - - - - - - A. J. Eardley
University of Michigan, Ann Arbor
Secretary-Treasurer - - - Edward J. Baltrusaitis
Box 811, Saginaw
Business Manager - - - - Gordon H. Pringle
Ohio Oil Company, Mt. Pleasant

Meetings: Second Wednesday of month at 6:30 P.M., from November to April. Informal dinner followed by discussions. Meetings held in rotation, at Lansing, Mt. Pleasant, Ann Arbor, Grand Rapids. Visiting geologists are welcome.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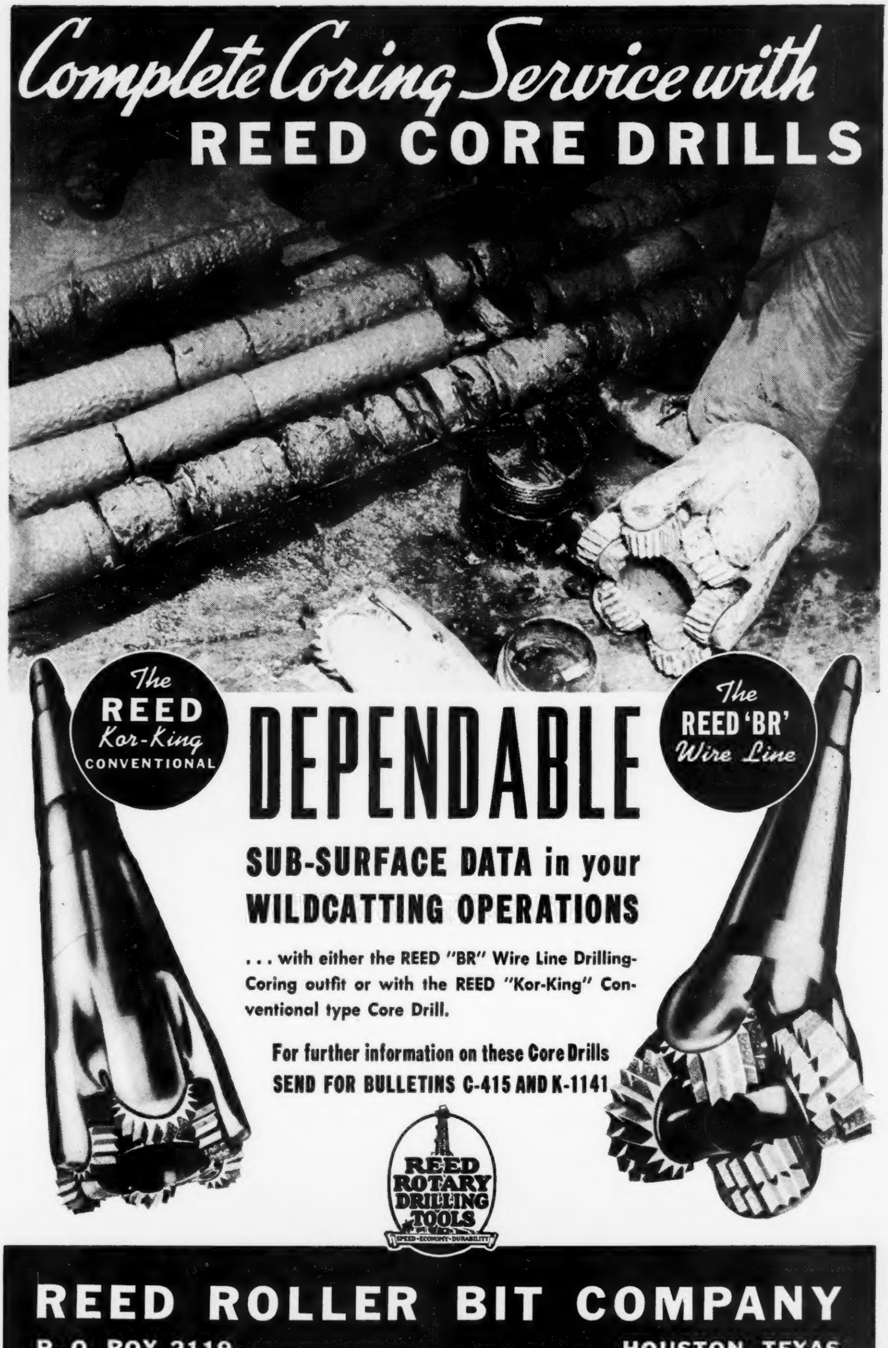
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